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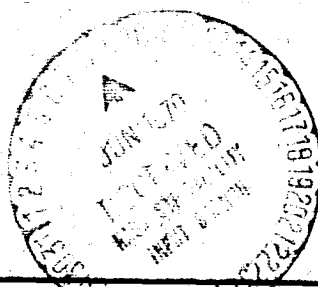
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A VERSATILE, LOW COST
TECHNIQUE FOR WIRING
SPACECRAFT ELECTRONIC
CIRCUITS

H. Chernikoff
M. Tharpe
L. Pack

Space Electronics Branch
Information Processing Division

July 1969

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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H. Chernikoff, M. Tharpe, and L. Pack

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ABSTRACT

This document describes a flight hardware packaging technique used by the Space Electronics Branch in the assembly of the Auxiliary Command Memory Unit (ACMU) for the OAO-B spacecraft. The technique is a departure from the use of printed circuits and has met all the stringent demands required in the assembly of space hardware.

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INTRODUCTION

This paper describes a technique for interconnecting integrated circuit (IC) flatpacks into a dense package suitable for flight applications. This manual method, which has been used successfully in the assembly of the Auxiliary Command Memory Unit (ACMU) for the OAO-B spacecraft, is adaptable to automation; however, it should only be used for low-volume hardware production.

Originally, the ACMU was to be assembled using the Microstick* technique; i.e., flatpacks were to be welded into modules that would duplicate certain printed circuit (PC) cards used for breadboarding. However, the manufacturer could not deliver acceptable flatpacks within the required schedule because of a metallization problem and with Microsticks, the flatpacks must be ready before fabrication can start. Consequently, another technique was needed that would allow the flatpacks to be delivered several months late without a resultant delay in the scheduled delivery of the ACMU flight system.

The technique chosen, which had been developed by the Aerojet General Corporation, allowed all boards to be wired and the wiring checked for errors prior to the mounting of flatpacks. After correcting all wiring errors, the flatpacks are mounted and soldered in place. The wiring appears on one side of the board and the components on the other.

This report is intended to serve as an informative review of a novel approach to electronic circuit packaging, as well as a specification for assembly of flight hardware without the use of printed circuits. As such, it is comprehensive and lengthy, but is so arranged that the detailed assembly instructions need be read only by those wishing to utilize this approach. The salient features of the technique described herein are:

- o It is flexible so that last-minute design changes can be incorporated with relative ease.
- o It allows access to every electrical point within the system during checkout.
- o It is inexpensive, requiring few special tools and a minimum of artwork (wiring is performed from a printed wiring list).
- o It can be automated, if required, through the use of a numerically-controlled X-Y table and all welded construction.
- o It utilizes point-to-point wiring which requires no multi-layer P.C. boards.

* "Microstick" is a trade name used by Electronic Engineering Company of California (EECO) Santa Anna, California.

- o No internal connectors are used.
- o Standard components as well as integrated circuits can be accommodated with ease.

The authors believe that this approach has merit, particularly for spacecraft hardware, in that it has a short turn-around time, can be easily modified to incorporate late design changes, and is suitable for limited volume production.

PACKAGING CONCEPTS

Basic Design

This packaging method is basically a point-to-point wiring technique for IC flatpacks and discrete components. Solid insulated wires are inserted into terminals and soldered directly through their insulation. Component leads are then inserted over these previously soldered wires and soldered to the same terminals.

Figure 1 depicts a mounted flatpack showing three items on which this design is based. These are:

- o A hollow bifurcated terminal,
- o Solid copper insulated 32-gauge "magnet wire", and
- o A glass epoxy board with 0.025-inch diameter holes pre-drilled on 0.050-inch centers.

Table 1 lists all materials used in the package assembly. With the exception of the boards, all are standard, off-the-shelf catalog items.

Although the board material is a standard catalog item, the particular pattern of the pre-drilled holes and the dimensions for the ACMU design require that the boards be obtained through special procurement. The board size, 6.5 x 5.5 x 0.06 inches, was designed to conform to a Microstick packaging concept. Using a high-speed drill, the pre-drilled boards facilitate fast and accurate enlargement of selected holes for the bifurcated terminals. The staggered pattern of terminals (See Figure 1) permit close flatpack placement which provides the greatest flatpack-density per board. It was necessary to drill the entire board because of:

- o the number of wires required for interconnections,
- o the number of wire ends that required termination, and
- o the desired distribution pattern required for wire build-up.

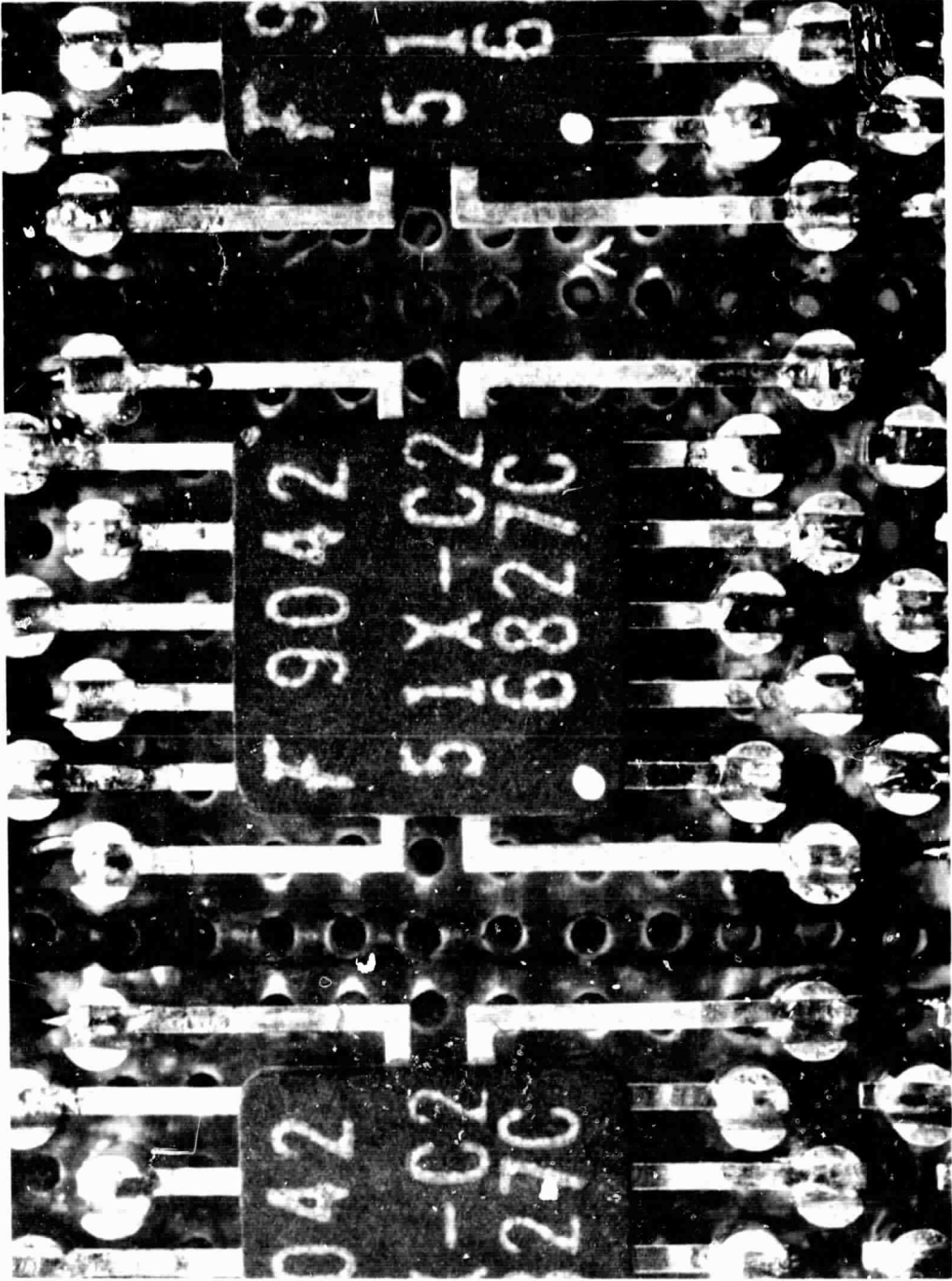


Figure 1. Flatpack Board Showing Materials Used and Terminal Pattern

As shown in Figures 2 and 3, all components are mounted on one side of the board, with the wire on the other side. Using the new technique, an increase of two boards over the Microstick technique was necessary to mount the flatpacks.

Table 1

MATERIALS REQUIRED FOR ASSEMBLY

Material	Manufacturer	Part No.	Common Name
Epoxy Glass Board	General Electric	G10	Printed Circuit Board Material
Bifurcated Terminals	USECO	2065B	Bifurcated
Flexible Cable	Digital Sensors, Inc.	5268	Flex-Cable
Soderon polyurethane-insulated wire 32 gauge	Essex Wire Corp.		Magnet Wire
Teflon insulated standard wire 26 gauge	General Cable Corp.		Hook up wire
Clear silicone encapsulating compound	General Electric	RTV-602	RTV-602

Design Flexibility

This technique is probably one of the most basic and flexible approaches that exists for construction of flight electronic circuitry. It is basic in that the complete unit can be assembled using standard catalog tools and materials by personnel possessing basic flight hardware assembly skills. The Appendix contains a full discussion of assembly, final packaging, and environmental testing techniques. It is flexible because design changes can be easily incorporated at any stage of assembly by adding and/or deleting wires and components with minor disturbance to existing circuitry. Changes are incorporated using the same technique as required for existing circuitry, therefore, reliability is not compromised. Also, it resembles the breadboard technique that is used, and therefore: the wire runs list for the

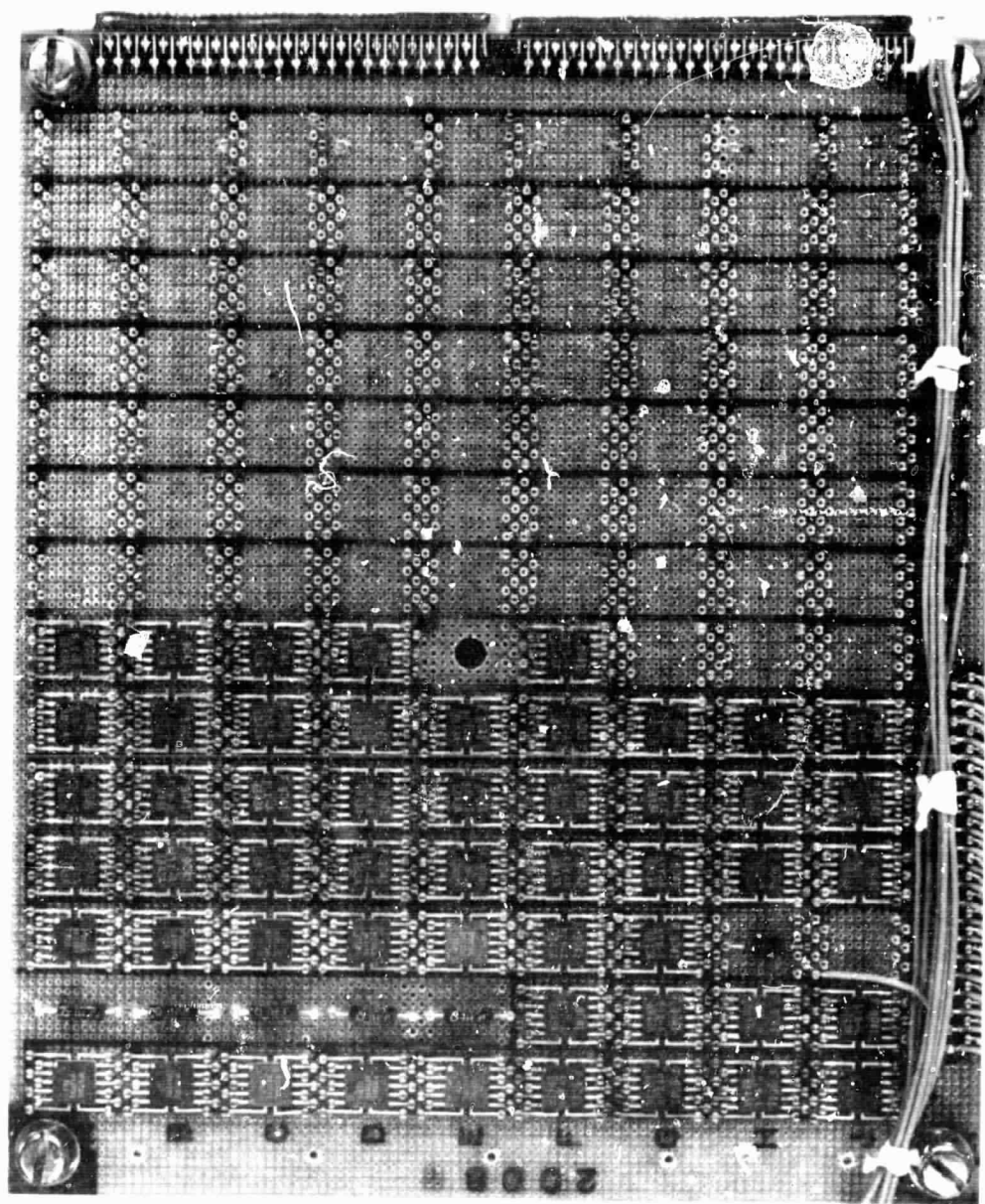


Figure 2. Component Side of Flatpack Board

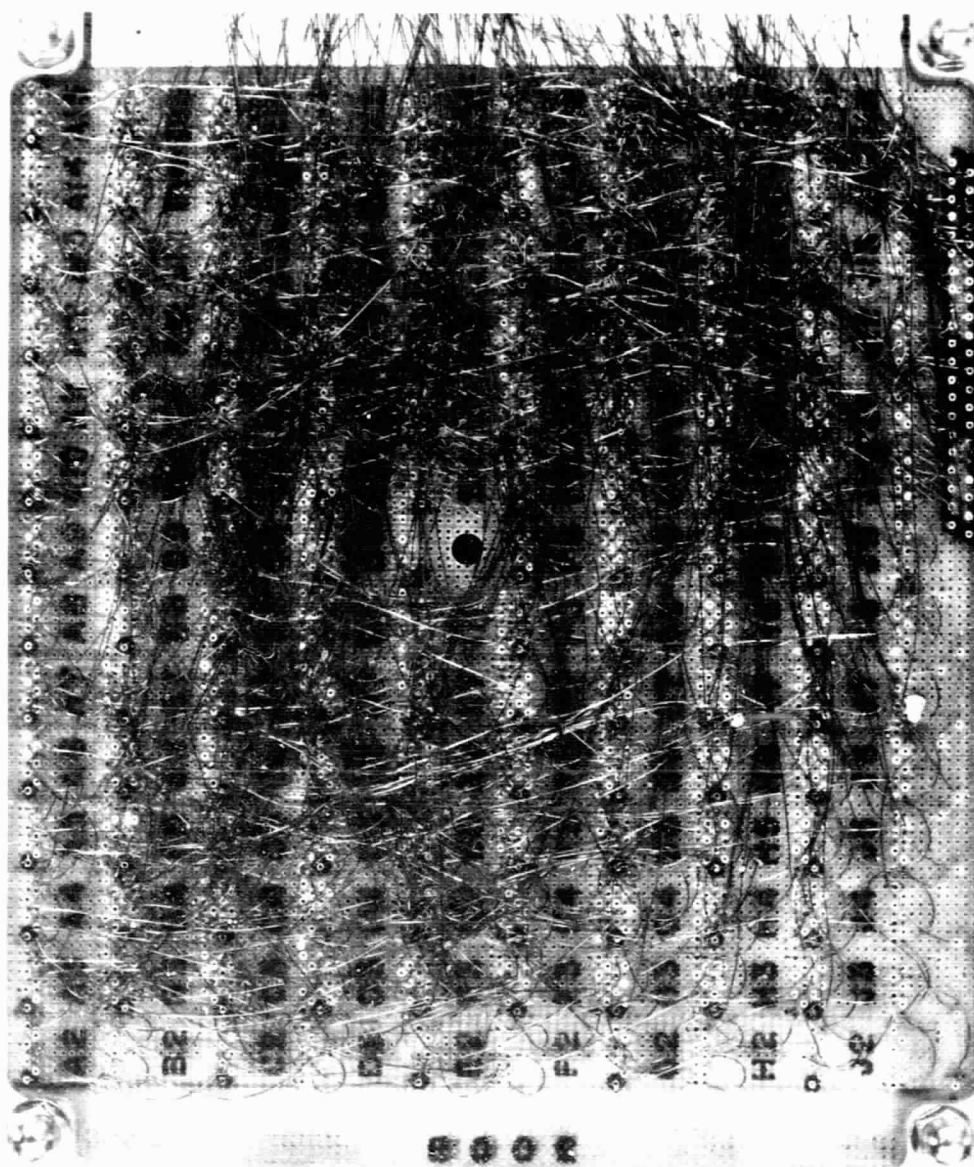


Figure 3. Wire Side of Flatpack Board

flight unit is identical to that for the breadboard; and each flatpack in the flight unit corresponds directly to a dual-in-line package used in the breadboard system. Flexibility is maintained during fabrication because this technique allows for a parallel operation; i.e., the flatpacks can be tested at the same time that the terminals are mounted and the wiring is completed, soldered, and checked. The flatpacks are then mounted on boards and the system checked. Fabrication by a Microstick technique, on the other hand, is a serial operation; i.e., 1) the flatpacks are tested and assembled in a Microstick, 2) the Microstick is tested, 3) the Microsticks are placed in a system, and 4) the system is tested.

Flexibility in system expansion is provided by leaving room for additional components. As shown in Figure 2, space has been provided for the addition of up to 68 flatpacks or other components as required.

Flexibility in unit repair is provided because replacement of only a single component is required. In the Microstick technique, repair required replacement of a complete stick containing from 7 to 12 flatpacks.

Reliability

System reliability was enhanced by the following:

- o Performing a two-step or parallel soldering operation, thereby ensuring that a positive electrical connection was made by utilizing either or both of the following alternate paths: component lead-to-terminal-to-wire or component lead-to-wire.
- o Replacing all terminals with either splits in the swaged end or with defective swages.
- o Carefully threading wires and discarding wire cuttings removed during the threading operation.
- o Connecting all electrically common points in a circuit to one common unbroken wire.
- o Visually inspecting boards with a 10-15 power binocular microscope upon completion of each fabrication phase.
- o Threading wires with unlike signals back through different holes in the board.
- o Employing conscientious assembly personnel and providing close supervision of them.
- o Ensuring that threaded wires are not taut and that sufficient stress relief exists in the wire bends.

- o Utilizing careful soldering techniques (as described in the paragraph on soldering).
- o Maintaining a minimum number of board-to-board interconnects.

Cost

This technique results in near maximum economy in production cost. However, because it is a hand-assembled technique, its economy is realized only in low-volume production. The package design costs are less when compared to PC boards and Microsticks because:

- o Layout is easier and faster and circuit cross-over problems are eliminated.
- o Printed circuit artwork is not required.
- o Design changes can be readily incorporated.

The approximate average cost per flatpack using this technique is \$8.00 to \$10.00, including the necessary programming to generate the wire runs list.

FUTURE DEVELOPMENTS

Heat Dissipation

The packaging method described in this report used only low-powered circuits and therefore, heat dissipation posed no great problem. However, future units to be packaged could use high-powered as well as low-powered circuits. A heat dissipating method that might be employed would be the use of copper plating on both sides of the boards. This would actually be printed circuit material covering most of the area, except where the pins are located.

The copper plating would act as a heat sink on the component side as well as providing a low-impedance B+ and ground bus. The IC's would be bonded to the copper, thus distributing the heat generated by the entire board. The overall heat dissipation needed would not be very high, thus minimizing the problem of heat removal.

Another method of removing the heat might utilize flexible copper conductors running from the boards to the packaging base and then to the external world.

Automation

Future techniques in this area will incorporate use of a numerically controlled X-Y positioning system and an automatic welding system. Combining these two systems will permit automatic positioning of the board

under the weldhead using a computer-generated tape and automatic wire feed. An operator, observing through a 10-15 power binocular microscope that the terminal to be welded is centered under the electrode, would depress a foot switch to bring the head down and make the weld. Next, the operator will press a button on the X-Y console to move to the next pin location and repeat the operation. This system will both permit faster operation and reduce the possibility of error.

Tools

A tool used for inserting terminals into boards is shown in Figure 4. If this tool is utilized in the fabrication process for future flight hardware, it will reduce the time required to complete terminal mounting compared to the ACMU assembly process; thus, a cost reduction can be effected using this tool. This will be possible because of the elimination of the terminal orientation step.

CONCLUSION

The advantages of this technique for assembly of flight hardware are:

- o It is inexpensive to build and the tooling is inexpensive
- o It is easily redesigned and repaired
- o It has a very high packaging density
- o The assembly method is similar to that used in breadboarding
- o The number of solder joints per flatpack lead is reduced to a minimum (i.e., an average of one solder joint per lead).

However, a method for improving the insulation stripping operation should be investigated. This could result in uniform joints and permit issuance of a specification document to ensure strict quality control.

It is especially useful for breadboarding of prototype work. For instance, if a welded system is to be built, an identical board design and breadboard system can be assembled using the solder technique. In addition, the same wiring list can be used for the welded system.

The Space Electronics Branch believes this technique is acceptable and investigations into improvements are continuing.

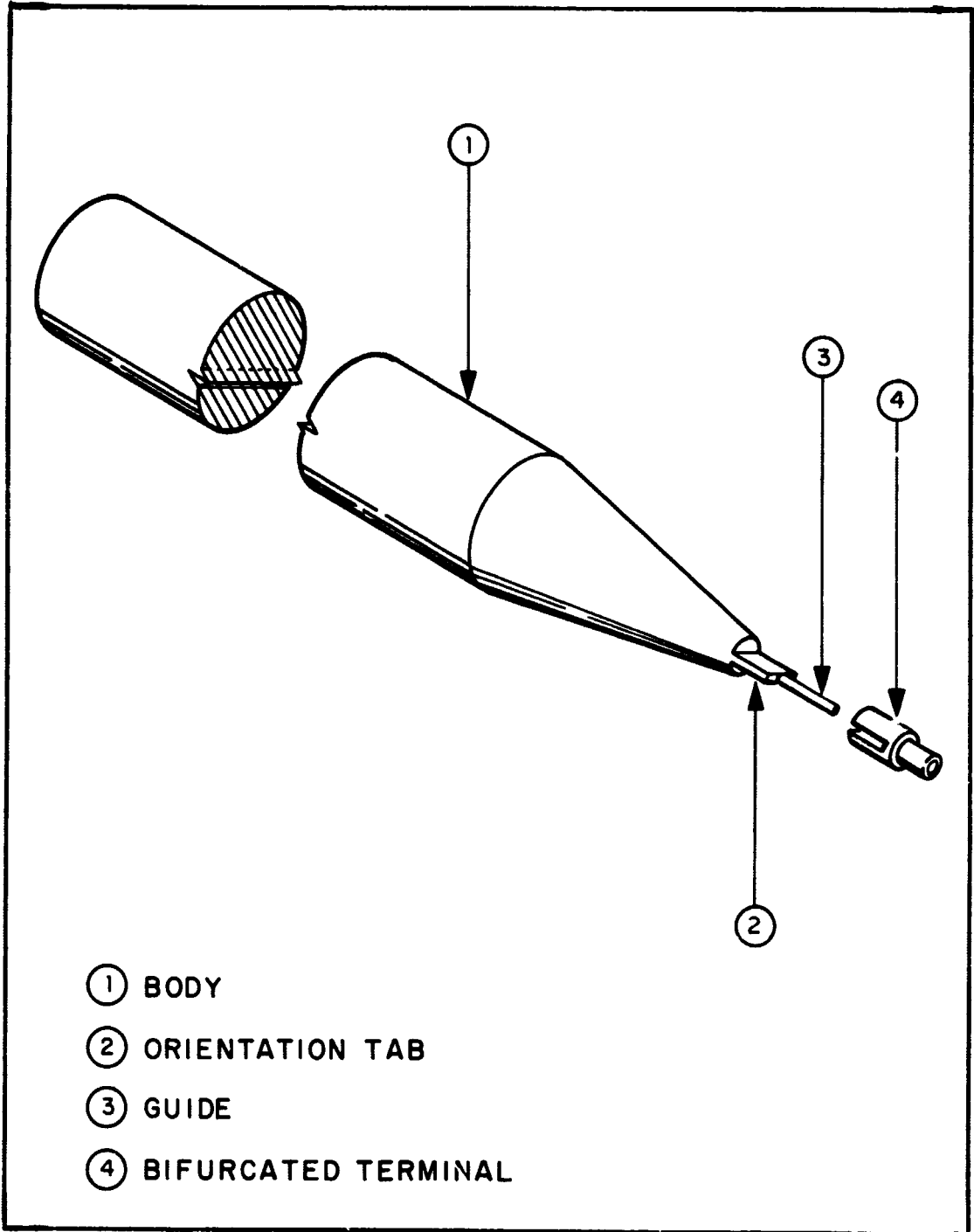


Figure 4. Tool for Future Terminal Mounting

APPENDIX

ASSEMBLY, FINAL PACKAGING AND ENVIRONMENTAL TESTING

APPENDIX

ASSEMBLY, FINAL PACKAGING, AND ENVIRONMENTAL TESTING

ASSEMBLY

The ACMU assembly was facilitated because the originally designed Microstick housing was not changed for the new technique. The final outside dimensions were maintained and the same size boards for component mounting and wiring were used. An increase in the number of boards resulted from mounting the flatpack as illustrated in Figure 1, and not on edge as in the Microstick technique.

The entire assembly, with the exception of mounting and soldering components, was completed at the Space Electronics Branch. The soldering operation was performed under contract because:

- o The available soldering system at Goddard lacked pressure and heat regulation to the degree required for this operation.
- o A parallel soldering operation was required because of limited time.
- o Experienced personnel for this phase of the operation were not available at Goddard.

As described in the soldering operation paragraph, pressure damage to a first set of boards required complete fabrication of a second set. However, this did not prevent delivery of the completed unit on schedule.

Members of the Space Electronics Branch observed the assembly procedures employed by Aerojet General. This enabled them to:

- o Develop improved methods of assembly
- o Avoid numerous problems that might have arisen by observing those that Aerojet was experiencing.

Tool Requirement

The various tools required to perform the board assembly are shown in Figures A1, A2, and A3 and listed in Table A1. Tools shown in Figure A1 are: surgical cutters, needle-nose pliers, diagonal cutters, and plastic soldering aid. A USECO Model "A" swage press, shown in Figure A2 was used to swage the terminals. The swage press was also used to operate the specially designed flatpack lead cutter shown attached to it in Figure A2. The two pairs of diagonal cutters that have been modified to trim the flatpack leads to the proper length are shown in Figure A3, as is the guide in which the flatpacks are inserted for cutting. These tools are fabricated as a backup to the cutting tool used with the swage press.

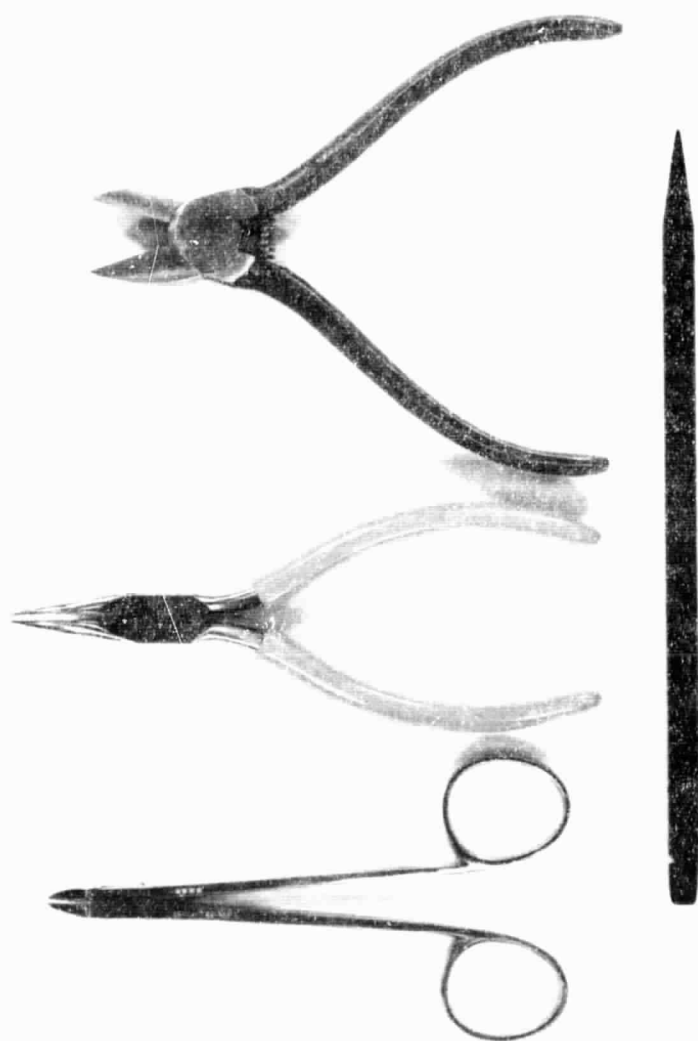


Figure A1. Wiring Tools

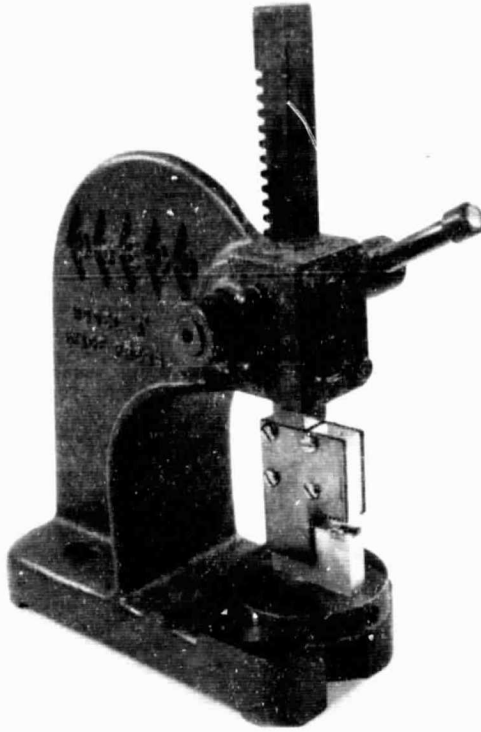


Figure A2. Swage Press with Flatpack Lead Cutter



Figure A3. Modified Diagonal Cutters and Guide

Table A1
ASSEMBLY TOOLS

Name	Part No.	Manufacturer
Diagonal cutters	S54RG	Diamond Tool
Plastic soldering aid	800G	Hexagon Electric Co.
Surgical cutters	36-464	Peer Co.
Swage press	Model "A"	USECO
Drill press	Model 105	USECO
Semi-automatic cutter	1308573	GSFC
Flat nose tweezers	861	Millers Forge
Needle-nose pliers	102	Wayne Co.
Soldering System:		Development Asso- ciates Control
Power Supply	TTC5001	
Soldering head and base	Model 3514	
10X Bausch & Lomb optics	Model 3511	

Table A2
EXAMPLE OF WIRE RUNS LIST

SIGNAL	MOD LOC	MOD PIN	MOD NO	CARD CON	CARD PIN
PETE	H14	4	2V	215	11
PETE	J28	6	3V	205	42
PETE	J28	9	3V	205	45
PETE	J28	10	3V	205	45
PETE	J28	2	3V	205	15
PETE	J28	3	3V	205	15
PETE	J28	11	3V	205	16

Table A2 (Cont'd)

SIGNAL	MOD LOC	MOD PIN	MOD NO	CARD CON	CARD PIN
PWRCL-	X1	83		2B3	
PWRCL-	K9	5		BJ5	
PWRCL-	H14	6	2V	215	8
PWRCL	G19	6	5V	213	26
PWRCL-	G19	13	5V	213	57
PWRCL-	H21	13	3H	212	43
PWRCL-	E25	2	1H	208	35
PWRCL-	A30	4	2V	202	1
PWCRL-	B30	4	3V	202	11
PWCRL-	C30	4	4V	202	20
PWCRL-	D30	4	5V	202	29
PWCRL	E30	4	6V	202	46
PWCRL-	B31	4	1V	201	43
PWCRL	E31	4	4V	201	20
PWCRL-	J31	4	1V	202	43
PWCRL-	X32	5			
RDCM	X 1	53		2V3	
RDCM	K 9	4	BJ5		
RDCM	A10	11	5H	218	54
RDCM	B10	5	1V	218	33
RDCM	D12	13	1V	216	35
RDCM	H12	12	5V	216	28
RDCM	J12	5	1H	217	8
RDCM	B13	8	2H	215	37
RDCM	F14	11	5V	214	27
RDCM	J25	2	5H	208	25
RDCM	B28	13	1H	205	32
RDCM	H28	6	2V	205	6
RDCM	F31	1	5V	201	26
RDCM-	B13	13	2H	215	9
RDCM-	H14	8	2V	215	9
RDCM-	H14	9	2V	215	9
READ	F10	1	5V	218	59
READ	F10	2	5V	218	59
READ	A24	9	6H	208	27

Not shown is the Development Associates Control soldering system used in the soldering operation. All tools are commercially available.

Wire Runs List

The use of a wire runs list instead of a wiring diagram in the flatpack board assembly was based on the wiring task complexity, ease of checking, and the need for reduction of wiring errors to a minimum.

In a complex wiring operation, the wire runs list will contain no errors if the transfer of logic diagram information to punched cards is correct. Using drawings to complete the same operation would require many overlays, and, because drawings are made by an individual copying the information from original drawings onto Mylar, the chances of making an error in the drawings and during the wiring operation is increased.

A wire runs list facilitates wiring and checking. Checking the most complex pair of boards required approximately 2.5 hours. The use of drawings would never permit such rapid checking because it is so difficult to follow wires that criss-cross. Drawings also require identification of installed wires. If great care is not exercised, the wrong wire will be marked off or a completed wire forgotten. The use of drawings in a complex wiring operation is cumbersome.

Flatpack board wiring was accomplished using a computerized wire runs list as illustrated in Table A2, the left three columns of which list:

- o SIGNAL; this column contains the signal name. The dash, or minus sign, after the signal indicates a NOT signal condition.
- o MOD LOC; this column contains the flatpack location, and/or the flat conductor cable connection location, and/or external connector connection location.
- o MOD PIN; this column contains the flatpack location, and/or the flat conductor cable connection terminal number, and/or the external connector connection terminal number.

The three columns on the right side of the wire runs list give the module or flatpack location on the PC card, the location of the PC card in the breadboard system, and the pin number of the 60-pin connector used on the PC card. Listed in the card connection column is the number of the pair of boards which the technician wires (Table A2 contains the 200-pair list). The 300-pair list was in another package so there was no possibility of wiring the wrong boards. Listing the breadboard wiring provided a cross-reference for troubleshooting purposes if a fault developed in the ACMU.

Figures A4, A5, and A6 show the numbering system used for locating flatpack terminals, terminal connections for the flat conductor cable and external connectors, and the flatpack position. Referring to Table 1 and Figures A4, A5, and A6 follow the threading of the PWRCL-signal. MOD LOC X1 indicates the flat conductor cable connector located on the left edge of the board as viewed from the wire side, and MOD PIN 83 indicates pin 83 of the connector (refer to Figures A5 and A6). MOD LOC H14 indicates a flatpack location, and MOD PIN denotes pin 6 of flatpack (refer to Figures A4 and A5). The connection from MOD LOC A30 to B30 is the crossover between the two boards - from board 200A to 200B. The terminating point X32 indicates the flat conductor cable connector located on the right edge of the 200B board. The MOD LOC numbers from X1 and X32 represent a single wire that is to be started at X1 and terminated at X32 after being threaded through all terminals from MOD PIN 83 to 5.

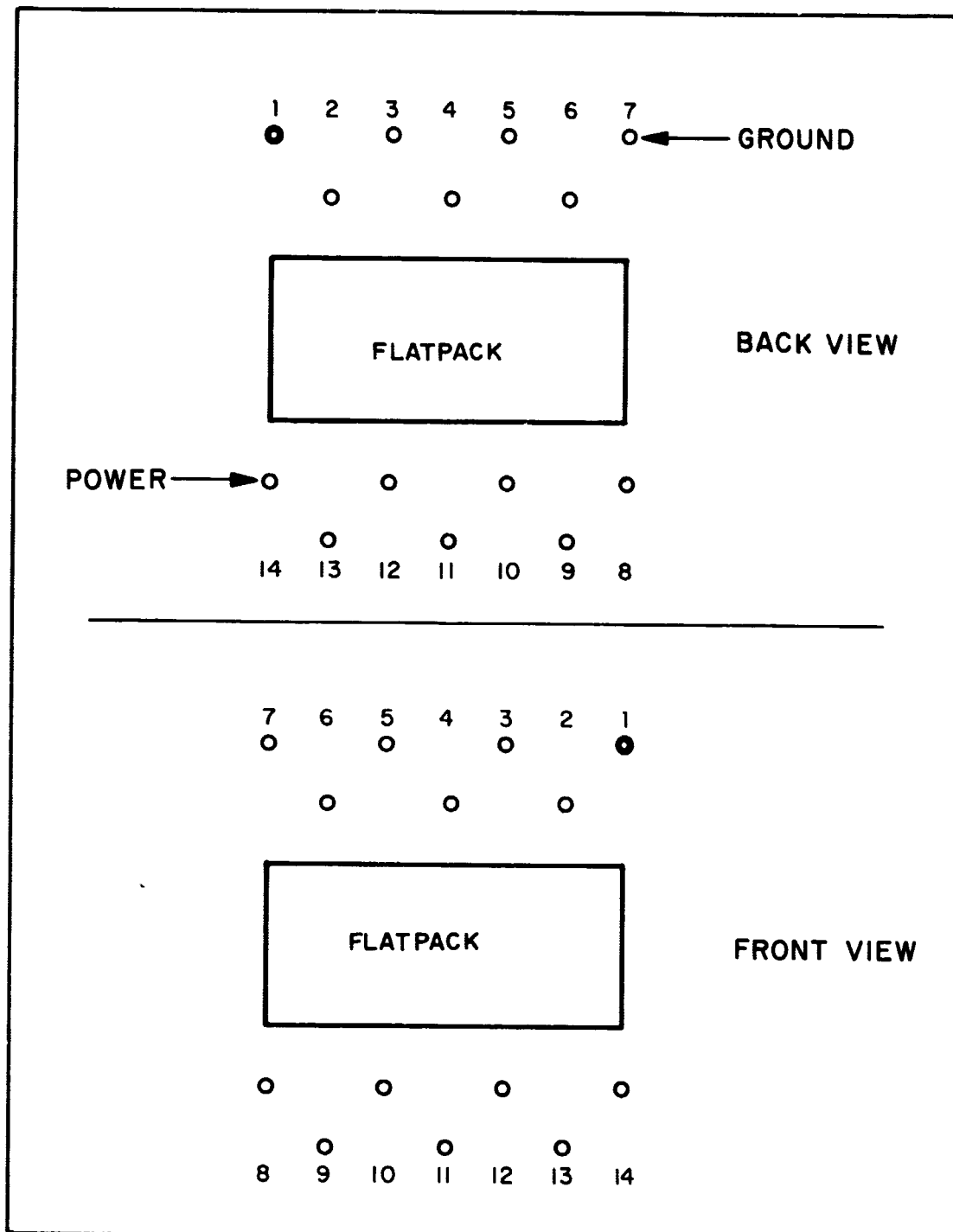


Figure A4. Flatpack Terminal Numbering

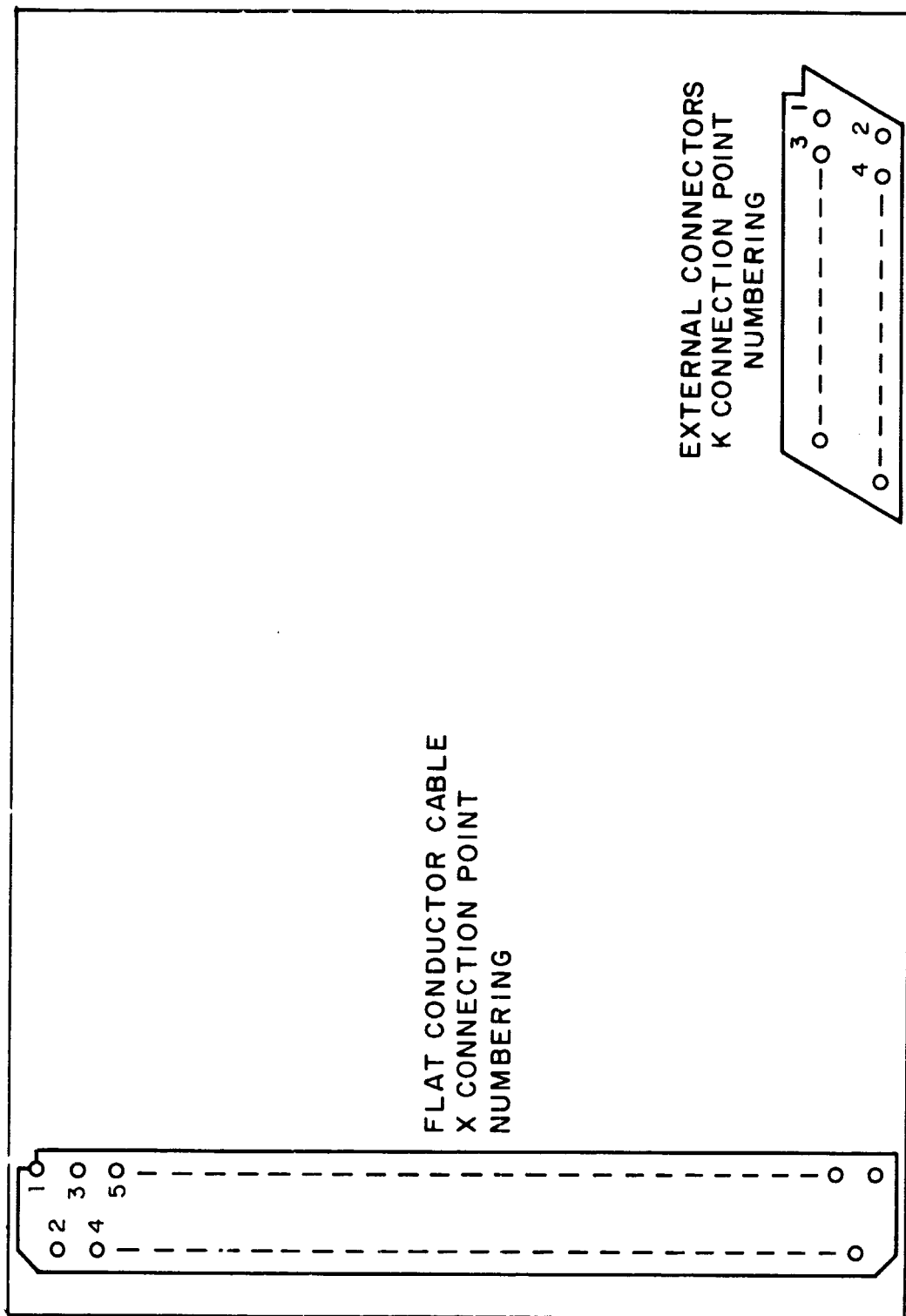


Figure A5. Board Terminal Numbering for External Connectors and Flat Conductor Cable

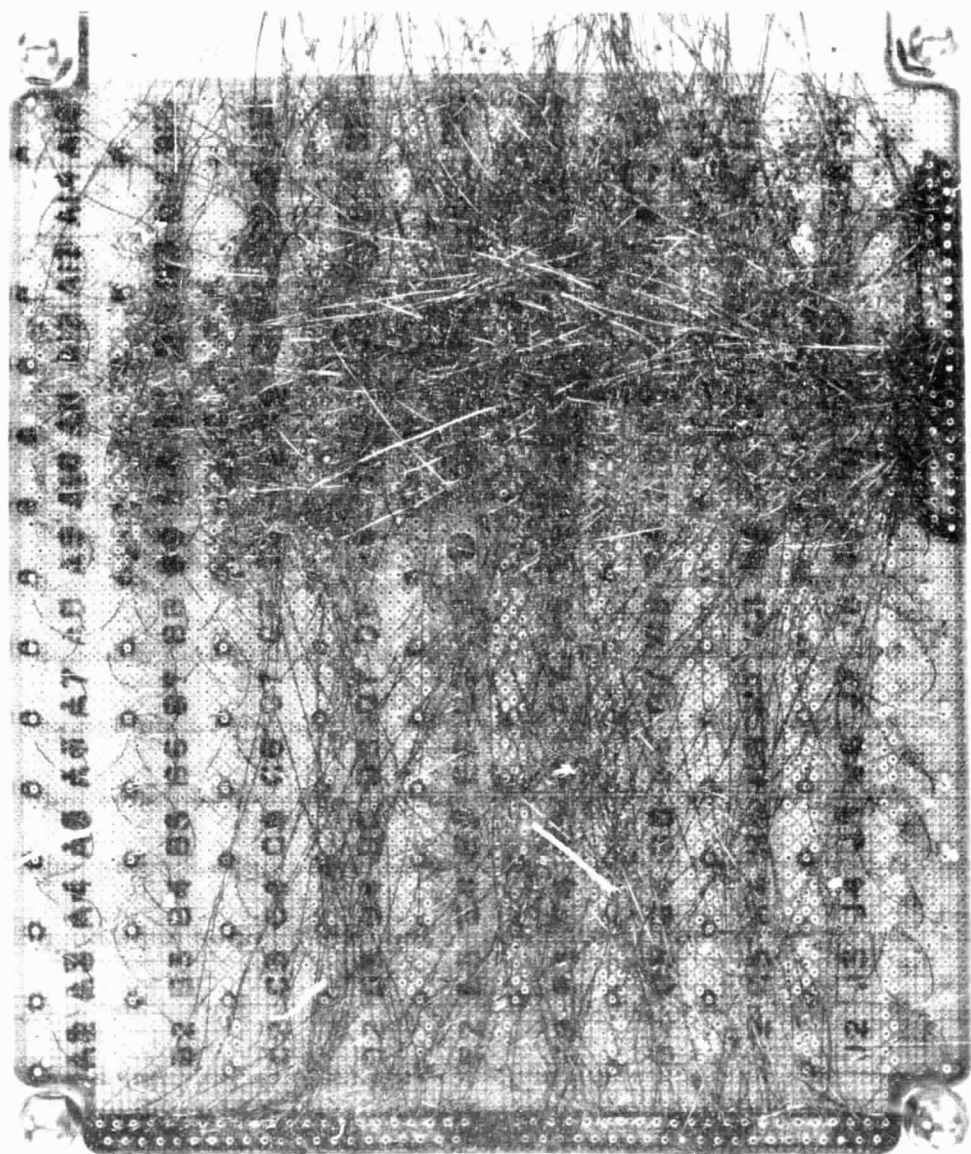


Figure A6. Back View of Board Showing Flatpack Locations

Board Preparation

After the decision was made to use the Aerojet approach in the package assembly, it was necessary to:

- o Identify the boards to enable cross-referencing back to the modular breadboard system.
- o Show where each flatpack is located on the board and the terminal numbering system used.
- o Devise a numbering system showing the location of both the flex-cable connection terminals and the terminals used to connect the boards to the external connectors.
- o Drill holes selected for terminal mounting to 0.033-inch diameter, and insert and swage terminals.

Identification of the two pairs of flatpack boards was accomplished by silk-screening the numbers 200A and 200B on one set and 300A and 300B on the other set. These numbers included all of the 200 and 300-level flatpack in the breadboard assembly. The hybrid board number 100 was the same as that used in the breadboard, and because it was assembled from drawings, it was not necessary to silk screen the number on the board. The relay board also did not require a number.

Each flatpack location was indicated by an alphanumeric code on the wire side of the flatpack boards (Figure A6). Location of each flatpack terminal was determined from Pin 1 which was identified with a black ring (Figure A4). The flex-cable connectors and the external connector positions on all boards except the relay board, were made alternately black and clear in groups of 10 pins to facilitate pin location (Figure A6). Pin 1 was marked by a notched clear area in the black portion, as shown in Figure A5. On the flatpack boards, the flex-cable connection areas were designated X1 and X32 and the external connection areas K9, K10, and K15. The X1 and X32 correspond to the first and last columns in a pair of boards. Connector areas were indicated on both sides of the boards to facilitate wiring.

Flatpack positions were shown by coordinates on the component side of the boards. Numbers from 1 to 32 were silk-screened on the bottom edge of the boards, and the letters A to K were silk-screened down the left edge of the boards. Pin 1 was again marked with a black ring. In addition, because the original technique involved the use of Microsticks, an area was outlined to correspond to a PC card in the breadboard system. This provided a second means of locating a given flatpack and was a precautionary measure against possible problem areas that might develop as assembly progressed. Documentation was later revised to directly reflect the position of a flatpack on the board, eliminating the intermediate step of outlining an area to correspond to a PC card.

Areas were outlined on both sides of the hybrid board and numbered 101 through 104, corresponding to PC cards in the breadboard system. Because this board and the relay board were both assembled from drawings, further silk screening was not required.

Upon completion of the silk screening, it was necessary to enlarge selected holes to accept the bifurcated terminal barrels. A high-speed drill was used to enlarge the terminal holes to 0.033-inch diameter. The board was held and the drill press was operated by hand. During this hole-enlargement operation on the first set of boards, it became necessary to change the drill bit halfway through the drilling of each board because of epoxy dulling of the drill bits. This dulling resulted in smaller hole diameters and burrs around the last holes that were drilled.

The next step was the insertion of terminals. The first procedure employed a single-board fixture held vertically in an adjustable vise. Terminal insertion was accomplished by holding the bifurcated end of the terminal with a small pair of flat-jawed tweezers and inserting the terminal in the selected hole. Terminal insertion on the second set of boards was accomplished by sliding the terminal over a drill bit held in a pin vise and then pushing the terminal through the selected hole. This method was not only faster, but supported the terminal and prevented damage to both board and terminal. Using the second method, it was necessary to go back after terminal insertion and align the terminals to accept component leads before swaging.

Swaging was attempted using the single board fixture containing a board with all terminals inserted. This method was unsuccessful because jarring or rough handling of the fixture caused terminals to fall out. The fixture was discarded and the final method adopted was to secure the board in the adjustable vise, fill two or three rows with terminals, remove the board, and then swage. Swaging was done by hand with a USECO Model "A" Swage Press. Care had to be exercised in aligning the board and in the amount of pressure applied on the swage. Excessive pressure and/or misalignment would result in a split or unsatisfactory roll in the swaged end of the terminal.

Upon completion of the swaging operation, the boards were visually inspected terminal-by-terminal under a 10- to 15-power binocular microscope. The criteria used to determine terminal replacement was:

- o Split in the roll of the swaged end
- o Slight roll in swaged end.

The terminals were not tested for tightness because the majority were nearly a press fit due to the decrease in drill diameter as it wore. The reason for replacing split or slightly rolled terminals was to ensure that the insulation on wires being inserted in the terminals would not be stripped. This eliminated the possibility of shorted wires during the

threading operation. Removal of a damaged terminal was accomplished by grasping the terminal bifurcated end as close to the board as possible with a pair of serrated needle-nose pliers, and then twisting and snapping it off. Then, the drill bit which had drilled the holes was used to push the broken terminal barrel out of the hole. Another terminal was inserted and swaged.

Although the bottom-section diameter of the swaging tool had been reduced to 0.090-inch, it was discovered during visual inspection that certain terminal groups had their edges shaved by the swaging tool. This shaving was a result of inconsistencies in the pattern of the pre-drilled holes. It caused small splinters of metal to be embedded in the epoxy boards, creating the possibility of shorts between terminals. These metal splinters were removed with a small pick tool. Each board was inspected at least twice for the metal splinters on a terminal-by-terminal basis.

After completion of visual inspection and correction of deficiencies, the boards were cleaned with alcohol.

The next board pair was secured in a fixture as shown in Figure A7a. The fixture was designed to:

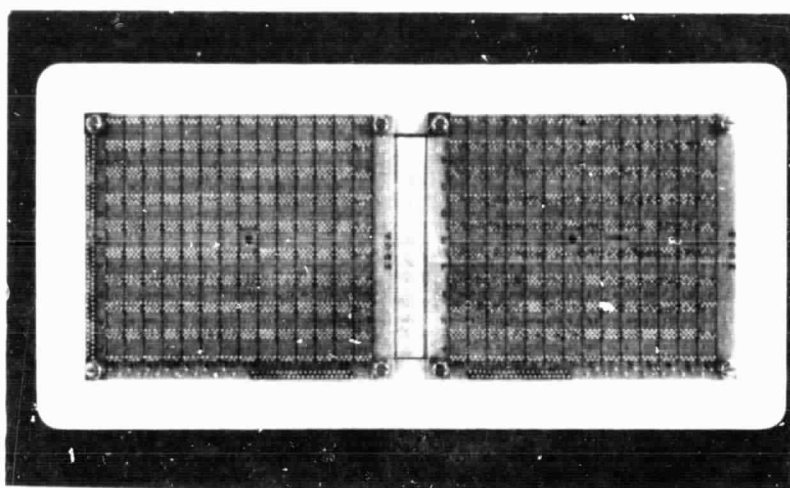
- o Provide the correct spacing between the boards for proper folding and final packaging.
- o Ensure careful board handling by eliminating the possibility of wire and component damage during assembly.

With the boards secured in the fixture, a strip of Mylar was placed between them and secured to the inside of each board (Figure A7a). The Mylar prevented the stressing of wires between the boards when removing the boards from the fixture for mounting in the final assembly fixture (Figure A15). This fixture was mounted vertically in an adjustable-positioning vise as shown in Figure A7b and the boards were ready for wire threading.

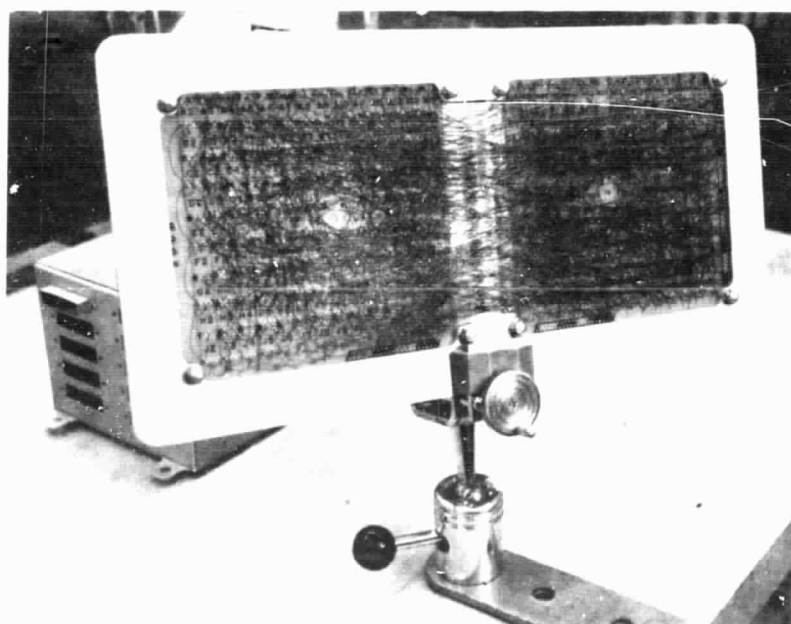
Method of Terminating Wires

Figure A8 illustrates the method used on the first set of boards for terminating the wires. Figure A9 shows the method on the second set of boards, which proved to be the most successful and reliable.

The method illustrated in Figure A8 was employed because it was in accordance with Aerojet General's specification. During the threading operation it was discovered that it was very easy to catch the end of the wire on a completed termination, thus bending it so the wire through the terminal was freestanding or looped (illustrated in Figure A8). This bend resulted in a wire termination that could be pushed out of the terminal by the solder tip during soldering, or pulled out during the threading operation. Soldering the loop was difficult because the wire



(A)



(B)

Figure A7. Fixture Used for Holding Boards in Wiring Procedure

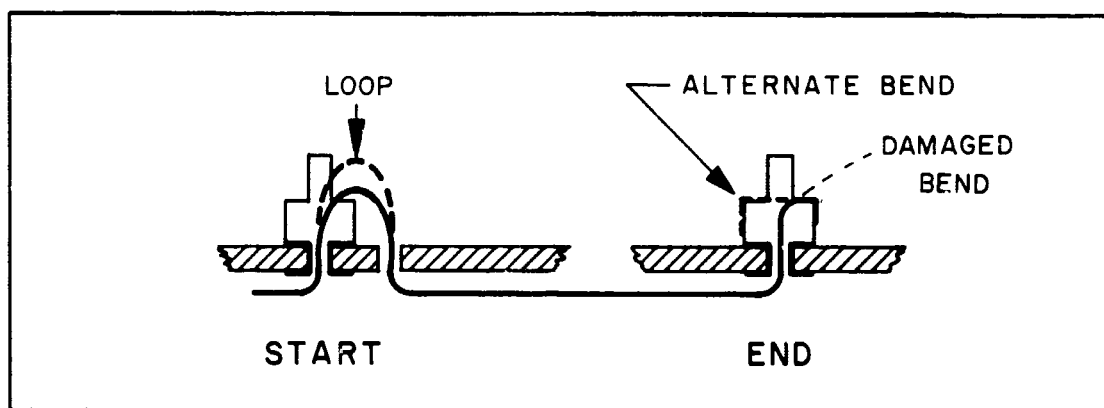


Figure A8. Method of Terminating Wire

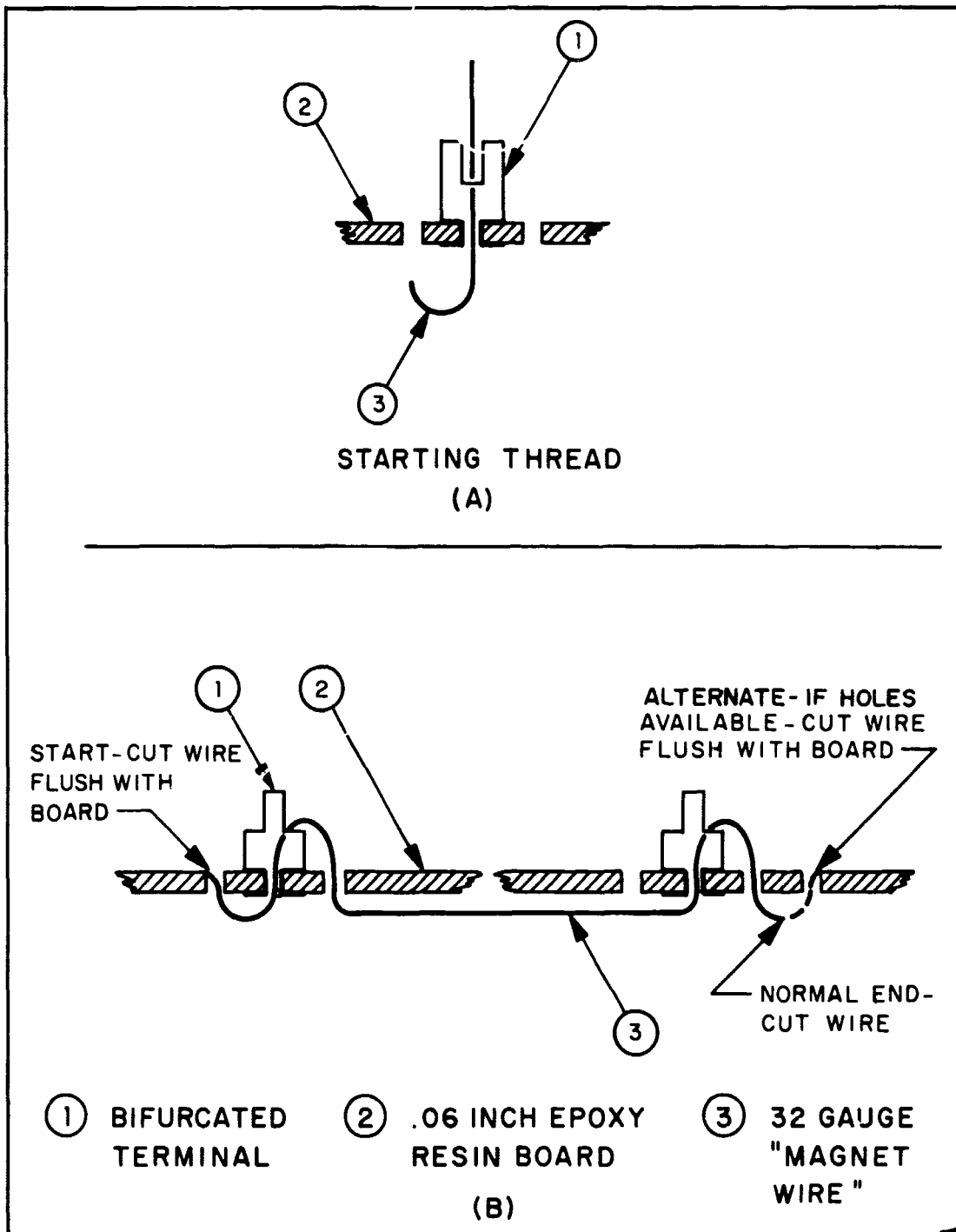


Figure A9. Final Method Used to Start and Terminate Wires

would spring back upon completion of the soldering operation creating an unsatisfactory joint. In the method illustrated in Figure A8, the start end bends can be completed after the wire has been threaded.

Flatpack Board Wiring

The first set of flatpack boards were wired from an alphabetically-sorted wiring list. All connections in row A were completed, then row B etc., until the boards were completed. This method created a large wire buildup between boards. For example, one signal wire with 32 connections had approximately 15 crossings between boards. When a second set of boards were to be wired, the wire list was sorted numerically (see Table A2) so that each wire was contained on the board and crossed between boards only once. The number of wires between boards was reduced by approximately one half by adopting the numeric sort. The power and ground functions were bussed both horizontally and vertically to reduce resistance. Horizontally, every row was bussed but vertically only every other column was bussed, resulting in the seven terminating points for power and ground at the bottom right edge of the flatpack board (refer to Figure A10). Capacitors in the right-hand column are used to filter noise generated by the circuit switching on the board. Each board contains these filter capacitors.

The wire used was 32-gauge, double-coated polyurethane, having diameter of 0.012 inches. This size was used to prevent excessive wire buildup and is sufficiently small to allow passage of two wires through a single terminal.

The point-to-point wiring allowed the use of a single continuous wire to hook all signals with the same name together. As shown in Figure A2, the wire entered the bottom of the swaged terminal and was pushed up through the terminal. It was then fed through the terminal by pulling on the bifurcated side while holding lightly on the swaged side. This method kept the wire insulation from coming in contact with the side of the terminal and being damaged. The start loop was pulled snug as illustrated in Figure A9. Then, the wire was fed back through an adjacent hole. This procedure was repeated until the wire was completely threaded.

In soldering the first set of boards, it was discovered that insulation melting could extend beyond the terminal base or back through the feed-through hole in the board. The melting of wire insulation could result in shorts between wires having unlike signals that had been fed back through the same board hole. Therefore, in wiring the second set of boards, like signals were fed through the same hole. This was accomplished by feeding the wires back through the adjacent hole close to the flatpack body (see Figure A11). This also allowed the flatpack lead to lay over and protect the wire permitting more space between flatpack terminals to facilitate any necessary repairs (see Figure A11).

In board wiring, it is important to leave an adequate wire loop not only for repair purposes (see Figure A11), but to keep wires from being

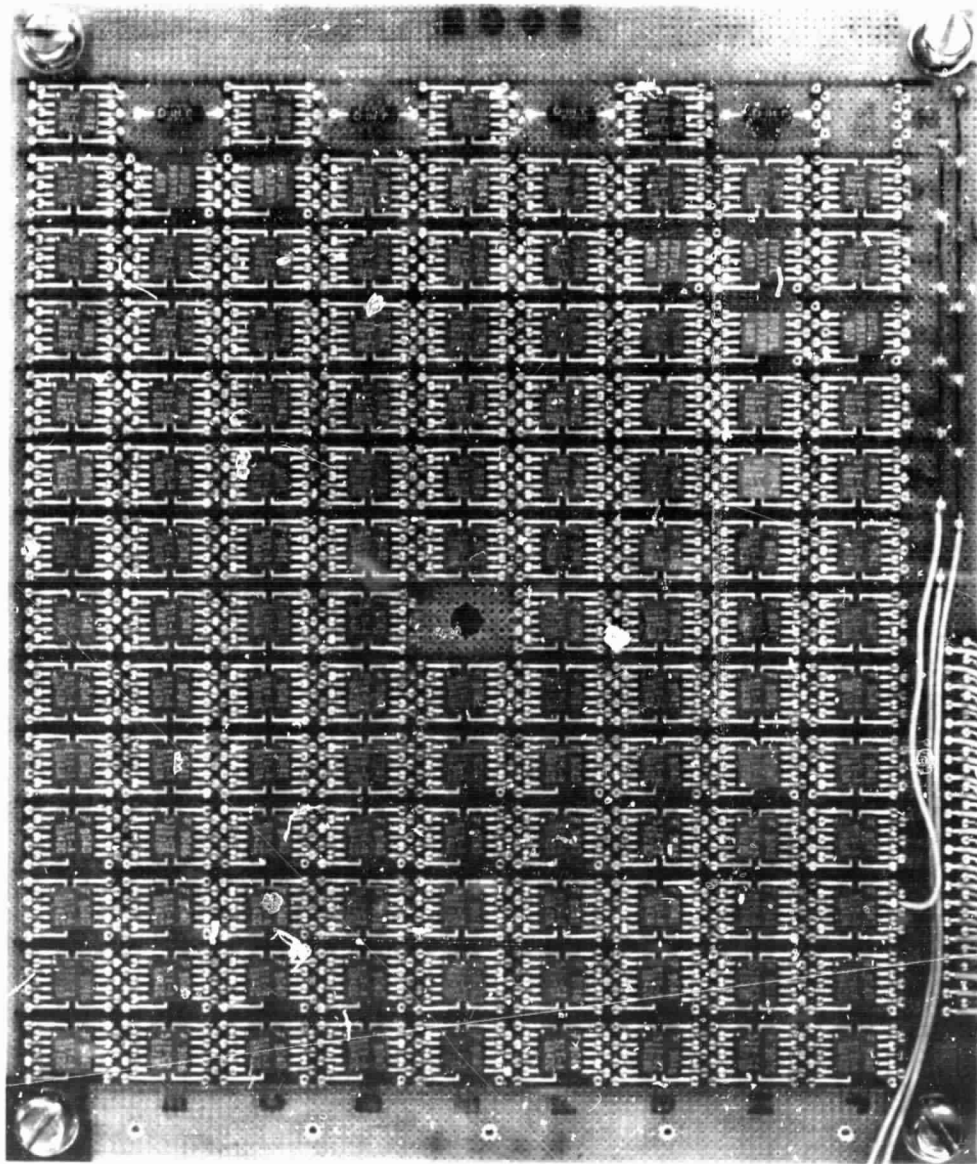


Figure A10. Power and Ground Bus

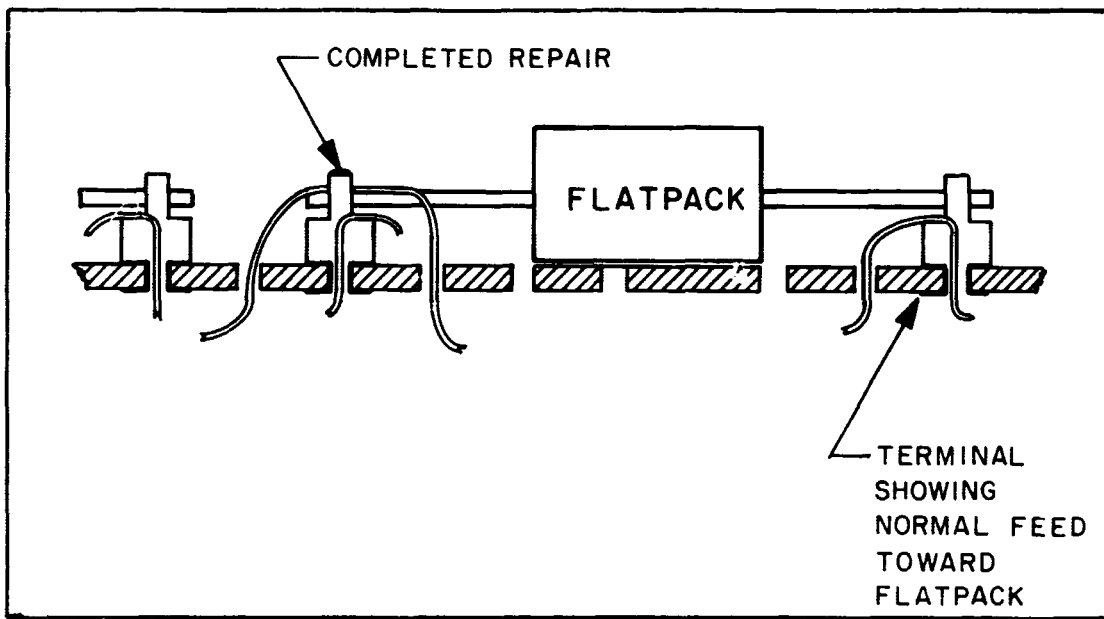


Figure All. Method of Repair and Feeding Wires Back Through Flatpack Board

pressed tightly together. This prevents shorts from developing between wires due to heat transfer during soldering. This also applies to the wires adjacent to the flared or swaged end of the terminal.

The wiring sequence utilized in the threading operation was as follows:

- o All B+ and ground wires were threaded
- o All signal runs containing intra-module connections were threaded

NOTE

The practice of threading the short loop connections first prevents the possibility of their trapping the longer run wires underneath.

- o All remaining wires were threaded, including wires between flatpacks, board pairs, and components.

NOTE

When wiring boards, it is recommended that some slack be left in each wire so they will not be pulled taut between pins. This facilitates the moving of wires in high-density areas to avoid damage.

Wires threaded each day were rechecked from point-to-point to ensure that no errors had been made. This was accomplished by following each wire with a plastic probe from point-to-point plus performing continuity and short tests with an ohmmeter after initial soldering. The boards were then ready for component mounting and soldering.

Hybrid and Relay Board Wiring

The hybrid board was wired from a set of drawing overlays and the relay board from a schematic diagram.

Wiring the relay board (Figure A12) was not difficult. It required the ability to read a relay schematic and careful wire handling. Larger size wire was connected to the relay terminals themselves because of the higher currents flowing to and from external circuits. This board required that the relays be mounted prior to wiring. Securing the relays to the board was accomplished with metal bands as illustrated in Figure A12.

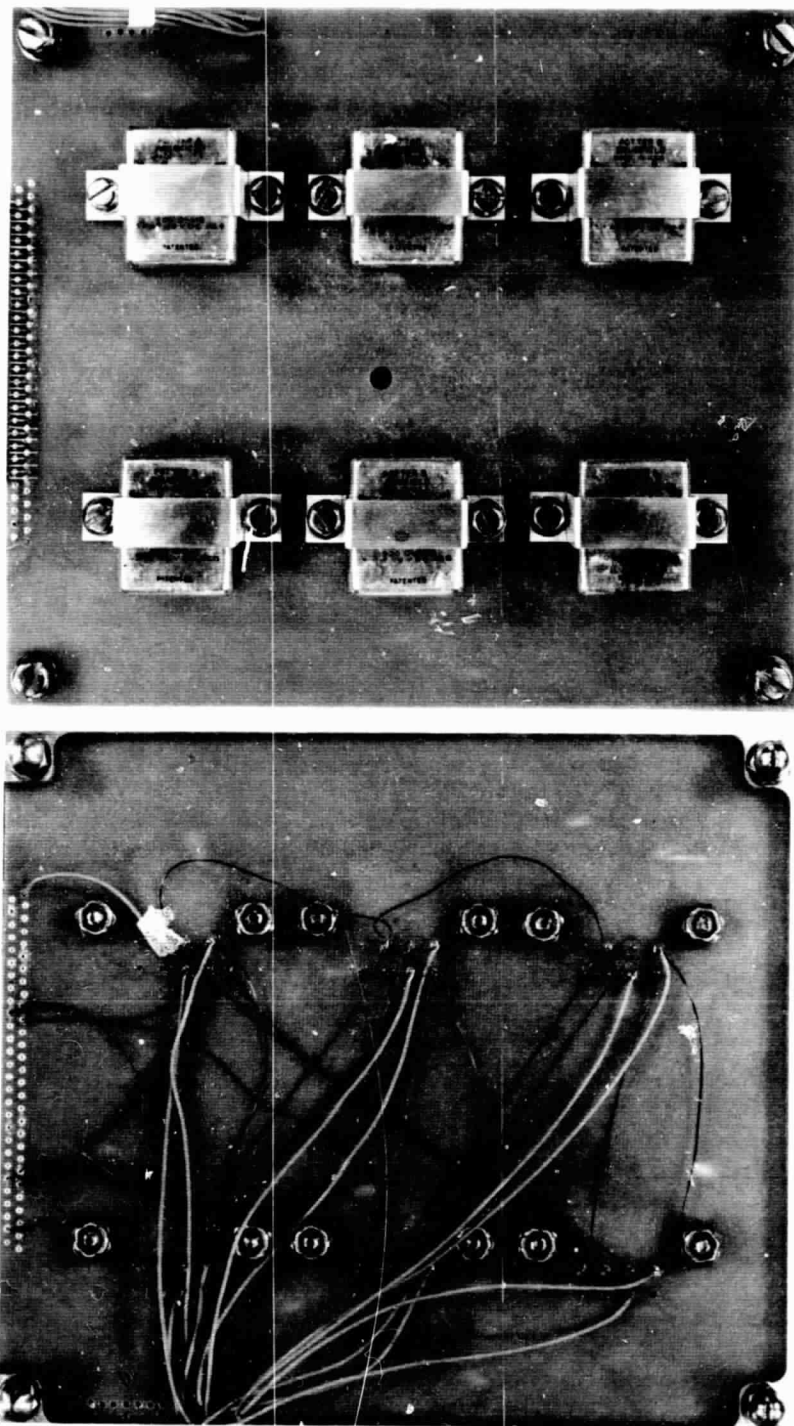


Figure A12. Component and Wire Side of Relay Board

Wiring the hybrid (Figure A13) was the most difficult, and resulted in having the most wiring errors because:

- o The board had no coordinates to show the location of various components; therefore, there was no convenient way of producing a wire runs list.
- o The board pattern was not regular, making it difficult to locate the correct holes during the threading operation.
- o Time did not permit researching other methods to better facilitate the wiring.
- o The drawing used was a point-to-point wiring diagram consisting of four layers of Mylar. One page contained all the power and ground connections; another, the internal connections within each given circuit; a third, the external connection between circuits; and a fourth, the wires to the external connections. This method allows one wire to continue from one page to another, making it difficult to trace.
- o The Mylar drawings were created from a paper worksheet; in transferring this information from the worksheet to the Mylar, tracing errors were made.
- o Some errors made on this board were not found until after the system had been completely assembled.

The following wire threading sequence was followed:

1. All B+ and ground wires
2. All short loop wires on the hybrid board
3. All remaining wires.

Each threaded wire was rechecked terminal-to-terminal after completion. The boards were ready for soldering.

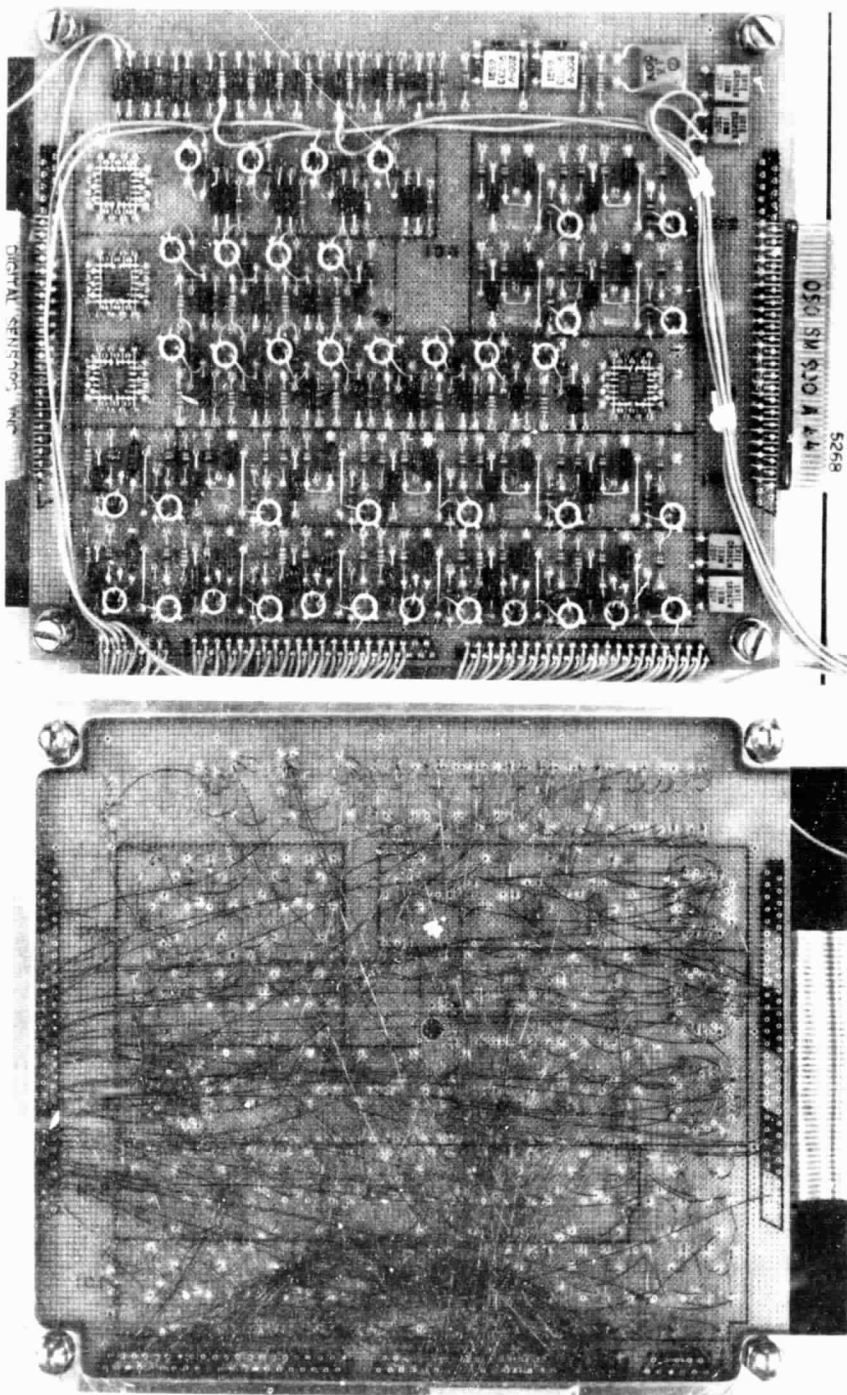


Figure A13. Component and Wire Side of Hybrid Board

Component Mounting and Soldering

Prior to mounting and soldering the flatpacks, the leads were cut to conform to the staggered terminal pattern. Because a tool with the required staggered pattern was not commercially available, a cutter (See Figure A14) was designed and fabricated at GSFC to accomplish the task. The two pairs of diagonal cutters and holder shown in Figure A3 were modified to serve as a backup for the swage cutter. Figure A13 shows the flatpack lead configuration after the cutting operation has been performed by both tools. The diagonal cutters have the advantage of being easy to use and inexpensive. They are ideal for low-volume applications. The semi-automatic cutter can be automated; it is accurate and protects the flatpack during the cutting operation.

Mounting all components on the component board was attempted by gluing them in place with Eastman 910. This was desirable because the diameter of the component leads was so small that components could easily be dislodged from the bifurcated terminals. Gluing proved impractical because it was difficult to apply a small amount of adhesive to the component and hold it in place until it dried. This was too laborious and offered no advantages because the unit was to be potted also. The method finally used was to mount a selected number of components and machine solder them. Then, the board was inspected on a terminal-by-terminal basis for damaged leads, wires, and unsatisfactory solder joints.

Soldering the hybrid and flatpack boards was a two-step operation as follows:

- o Soldering the completed wiring to the terminals before mounting components
- o Mounting and soldering components.

In comparison to the component-and-wire soldering method performed in one step, the two-step method allowed for the following:

- o A point-to-point electrical circuit check of the wiring prior to mounting components
- o Easier repair of damaged or incorrect wiring
- o Less possibility of component damage due to a reduced soldering heat cycle.

Damage to the first set of boards was discovered before completion of the first phase of the soldering operation, due to the practice of inspecting the boards after each operation.

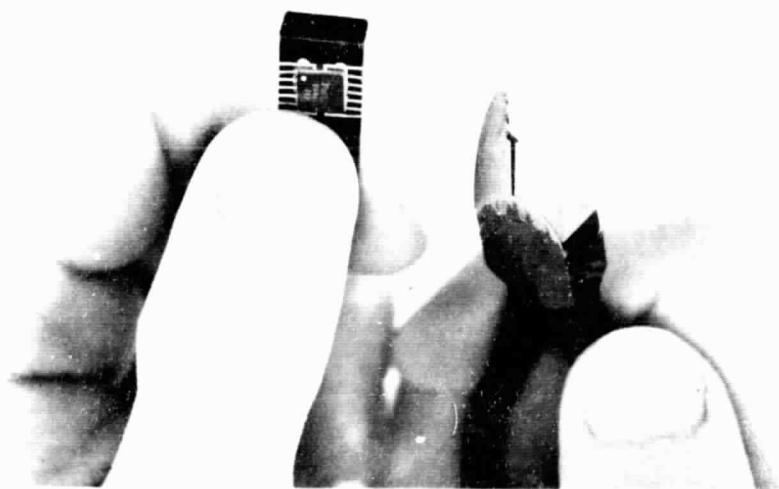
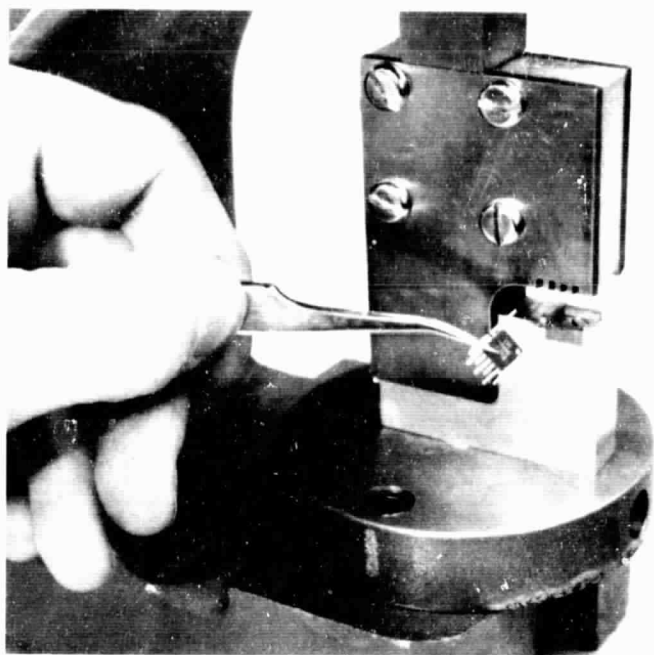


Figure A14. Results of Flatpack Lead Cutters

Damage resulted because the soldering machine's pressure control only regulated the pressure at which the machine fired or turned on, but did not allow for the maximum pressure setting that could be applied to the terminal. Thus, if the operator kept applying pressure on the foot pedal after the welder fired, there would be cut, nicked, or deformed wires. In addition, another undesirable feature of the machine was the inability to control the heater temperature or the rate at which it reached proper temperature. It was slow coming up to temperature, and then was not hot enough because the wire insulation, instead of vaporizing, melted and became a charred mass which remained on the wire and contaminated the solder that was deposited on the wire and terminal.

During the process of heating and melting the insulation from the wire prior to or during soldering, the silver plating on the terminals tended to oxidize slightly. This resulted in the solder not adhering to the terminal as well as it would to a solder-coated one. The silver-plated terminals were used because solder-coated ones were not available during assembly. The use of solder-coated terminals is highly recommended.

Before performing the second step of the soldering operation, the boards were inspected on both sides with a 10-15 power binocular microscope for evidence of adequate insulation stripping and wire damage. Continuity between wire and terminal plus adequate wire stripping were assured by the following procedures:

- o Performing a circuit check between wire and terminal. This assured sufficient insulation stripping, even if not apparent from a visual inspection.
- o Reworking some joints, even though electrical continuity was indicated, until bare wire was visible at some point on the terminal side. The insulation was stripped back from the terminal edge approximately 1/32 of an inch. This assured vaporization of the insulation.

The procedure of soldering one flatpack lead, then moving to the adjacent one had to be modified because heat from the adjacent lead was being transferred back to the previously soldered and still hot, lead. This heat transfer was due to the close proximity of the terminals, and, was not only being radiantly transferred, but also transferred through the epoxy board. The result was melting of the solder on the completed joint, thus lifting the terminal lead. Soldering the flatpack leads were completed on a vertical pattern, i.e., a lead on top of the flatpack, next a lead on the bottom, and so on down the board.

Electrical continuity between component and wire was now assured by the existence of two possible paths—component lead to wire, and component lead to terminal to wire. Ideally, continuity should be direct from component lead to wire, which should also exist using this method because there should be solder flow between the wire and

component lead. Continuity from component lead to terminal was checked by visual inspection to verify that component lead and terminal were actually soldered.

Upon completion of soldering the flatpack leads, the boards were inspected on a terminal-by-terminal basis which revealed some joints that required rework. During the reworking process it was discovered that leads could easily be nicked, stretched, bent, or broken if the operator brought the welder head down with any misalignment, especially toward the flatpack. This was also a direct result of not providing stress relief on the leads, which was not provided because proper tools were not available.

After discovery of this damage, the rework done by machine was stopped. All rework was then completed by hand, and it was found that the flatpacks could actually be soldered into position much faster than by machine. The joints appeared more shiny than machine joints, and it was easier to control the amount of solder deposited.

The relay board was soldered using a hand-iron. The first attempt produced some cold-solder joints because the iron was not hot enough to melt the insulation to the extent that a good joint could be obtained. This was corrected by using a 50-watt soldering iron having a relatively small tip.

Using a brush and spray, all boards were cleaned with alcohol and Freon to remove any contaminants. The brush was used to clean the component side, and the spray used to clean the wire side. Then, the boards were ready for mounting in the final assembly fixture.

NOTE

DO NOT use a brush to clean the wire side of the board because of possible damage to the wire.

Final Assembly

Figure A15 illustrates the board mounting in the final assembly fixture. This fixture was designed to:

- o Conform to the final folded configuration of the boards
- o Provide circuit testing and modification capability prior to final packaging
- o Permit folding into a "U" configuration for placement inside a terminal chamber used to perform preliminary tests
- o Facilitate handling as a unit while completing assembly.

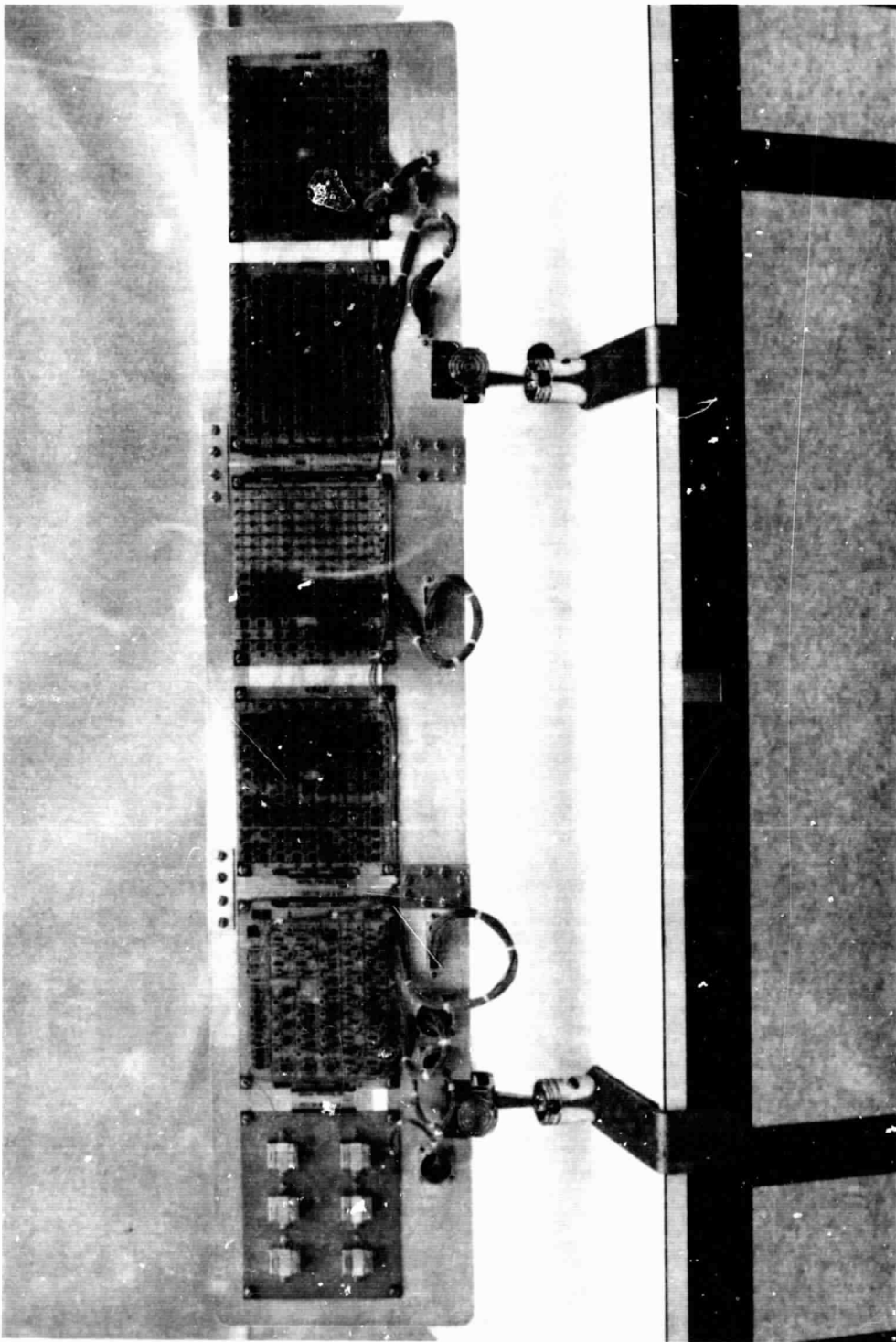


Figure A15. Boards Mounted in Final Assembly Fixture

The fixture was mounted in two adjustable vises which permitted horizontal as well as vertical placement. This facilitated inspection and repair.

With the boards secured in the fixture, the remaining task was to wire them to the external connectors with Teflon-insulated stranded wire, and the board pairs were connected with flexible flat conductor cables. Terminal and plug connections were hand-soldered.

Upon completion of assembly, the component side was brushed clean with 200-proof alcohol and the wire side was spray-cleaned with Freon.

The boards were inspected again under a 10-15 power binocular microscope for insulation damage to wires. All wires that appeared damaged were physically separated by a plastic or wooden probe and sprayed with a conformal coating of clear polyurethane. The polyurethane served to reinsulate damaged wires, removing the possibility of short. A coating of polyurethane was also sprayed on the component side. This coating also insulated the boards from any external conductive contaminants and tied down the wiring to prevent snagging during handling.

NOTE

The polyurethane conformal coating used has the characteristic of being heat stripable, e.g., at soldering iron temperature it will melt and flow away. This characteristic allows repairs to be made without using abrasives or chemicals.

Prior to application of the conformal coating, the Mylar areas on both the component and wire side were covered with a mask. This was necessary because the polyurethane increases the rigidity of both the wire and the Mylar, which conceivably could create problems during the folding operation.

The final assembly operation was then considered to be complete and the boards were ready for preliminary testing.

PRELIMINARY TESTING

Preliminary tests consisted of a system check in the clean room and a thermal test with the unit connected to a computer.

The clean room tests consisted of a power check and a limited functional logic check using signal generators. Two faulty transistors were located as a result of these tests; one was a manufacturing anomaly that had been missed during the screening process, and the other was damaged during the testing or application of power.

The terminal test was continued by having the fixture folded in a "U" shape and placed in the thermal chamber. Next, the system was connected to a computer, sent various commands, and exercised properly. A logic error and a wiring error were found during this testing phase. Hot and cold thermal testing was completed in two days and the complete preliminary testing was finished in seven days. The unit was then ready for final packaging.

FINAL PACKAGING

Final packaging of the boards was begun after completion of the preliminary tests. The boards were removed from the final assembly fixture and 3/8-inch spacers were secured to the bolt holes on the bottom and top of the boards with Eastman 910 adhesive. Particular care had to be exercised in securing the spacers to the center bolt holes because of the wire density. All wires surrounding the holes had to be re-positioned back from them far enough to eliminate any possibility of the spacers crimping the wires and/or nicking the insulation when the boards were secured in the housing.

Folding the boards was a two-man operation. It required one man to place and hold two Mylar strips on the spacers of one board while the other person folded a board over and secured the strips between the spacers by maintaining pressure on the boards. This procedure was followed until all boards were folded. Next the external connectors were mounted on the housing front panel. The folded boards were then placed in the housing and the five bolts inserted through the housing bottom up through the spacers, Mylar and boards. Finally, the folded boards were secured in place with five lock-on washers and nuts (Figure A16).

Spacers were used between the boards to provide proper build-up and to keep the boards at a proper height so they would not touch each other during periods of vibration. The Mylar layers between the boards served two purposes as follows:

- o They provided insulation against electrical shorts during periods of vibration
- o They aided in the removal of potting material whenever the boards had to be separated for repair or modification.

The use of two Mylar strips between boards provided the capability of unfolding the entire system, if necessary, to complete repairs and/or modifications.

Upon completion of mounting the boards in the housing, but before potting, ambient temperature tests were performed to ensure no damage had been caused by the folding operation. A clear plastic cover, as shown in Figure A17 was attached to the unit in preparation for potting

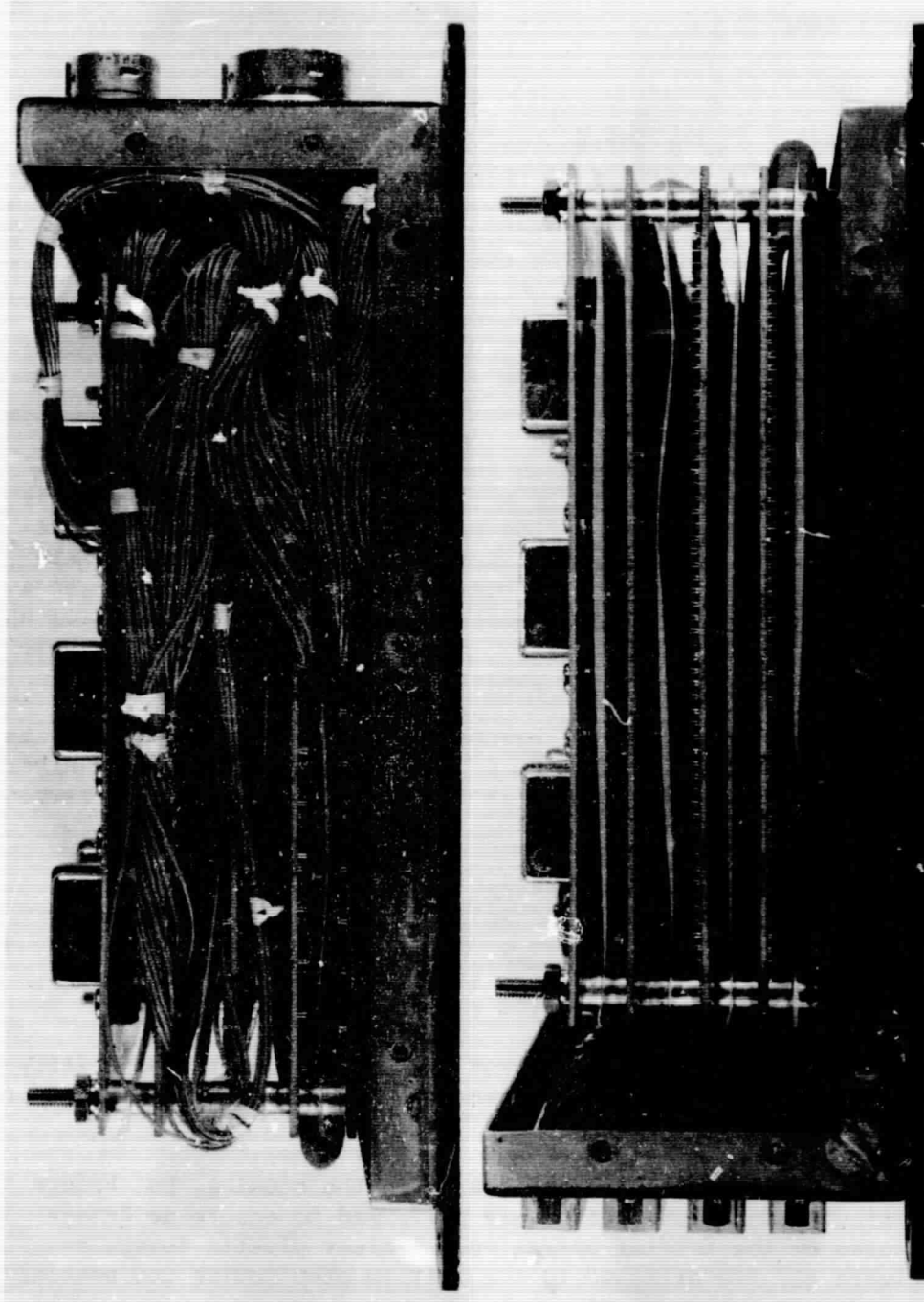


Figure A16. Side Views of Unit Prior to Potting

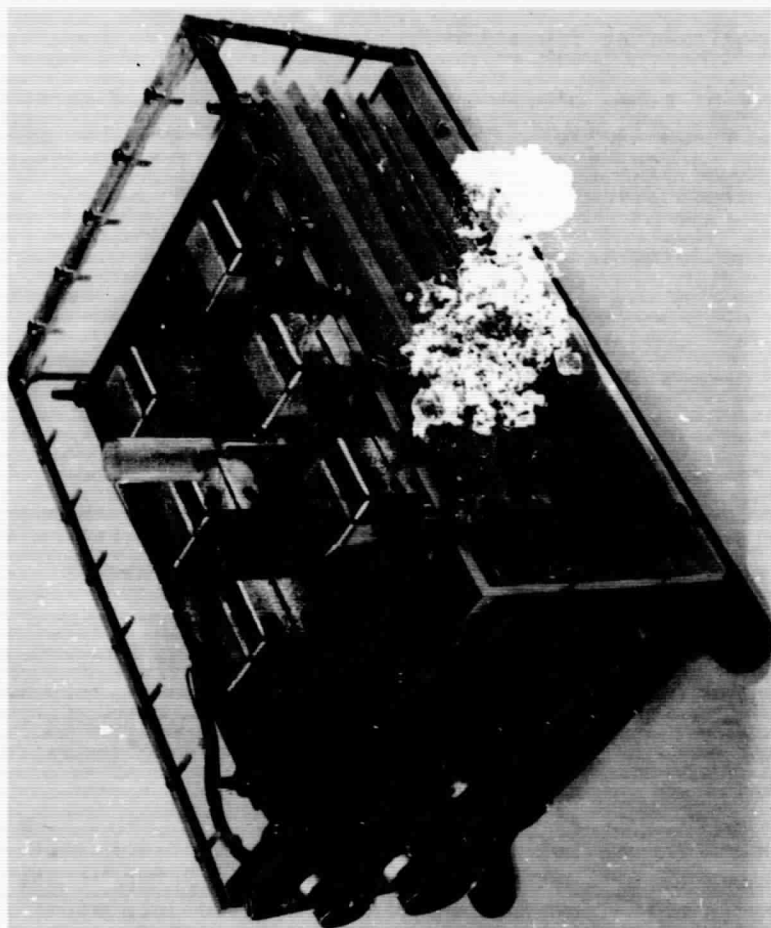


Figure A17. Unit with Plastic Cover Prior to Potting

after completion of the tests. During placement of this plastic cover over the unit, it was necessary to ensure that the external connector wires were not being pressed against any sharp metal corners or hardware, that they were laying relatively loose and free in the package. The main reason for this precaution is that the Teflon insulation will cold flow if it is resting on a sharp edge resulting in the possible development of an electrical short. In areas where this situation exists Kapton pressure-sensitive tape was wrapped around the particular metal edge to provide additional insulation should the Teflon coating cold flow.

Method of Limiting Vibration

A summary of other proven and unproven methods and materials used to lessen vibration in final packaging are herein outlined prior to describing the potting procedure chosen for the ACMU. Potting the ACMU with RTV-602 clear silicon rubber was determined by:

- o Previous experience
- o Lack of time to experiment with other materials.

Aerojet General did not use potting in a unit that was conformally coated and flown. The vibration problem in this unit was lessened because the boards used in this one were smaller in area than those in the ACMU. No attempt was made, due to time limitations to determine if the ACMU package could have been flown without encapsulant. If weight is a factor, the unit could probably be assembled using more bolts in the final assembly which would give a closer hole pattern, reducing resonance.

Aerojet General has also experimented with using foam. The procedure requires covering the board, or boards, with one mil plastic and then foaming. As the foam fills the void, it forces the plastic into all the small voids around the wires and components, thus producing a foam interface that conforms to the board surfaces. These foam pieces can then be precisely fitted and stacked between the boards.

This method allows for foaming of package sections instead of the entire package. No attempt was made to use this setup on the ACMU because time did not allow for experimentation to determine:

- o If the plastic would allow the foam to fully conform to the wire patterns and components, thus permitting a tight fit around them and reduction of component and wire vibration to an acceptable minimum.

- o The amount of pressure required to produce a pattern of wire and components on the foam that would result in a tight fit, and if this pressure was sufficient to cause damage.
- o The foam density required to properly secure the components and prevent them from breaking or puncturing the adjacent foam during periods of vibration.

The final weight of the ACMU was approximately nine pounds. This weight could have been reduced substantially by the use of foam or epoxy spheres in conjunction with the RTV potting.

ACMU Potting Procedure

Two reasons why RTV-602 is a popular material for potting are:

- o It is transparent and permits an internal view of the unit so that test points can be located easily.
- o It is self-adherent only, and can be removed easily, facilitating quick de-potting, repair, and re-potting.

The potting process involved mixing the RTV and placing it in a vacuum chamber to remove all air bubbles. Next, the ACMU was placed in the vacuum chamber with a tube connected through the vacuum system into the RTV. With the valve to the potting material closed, the vacuum system was turned on, evacuating the air from the ACMU. Then, the potting valve was opened and the potting material slowly filled the unit. The process was observed through the clear plastic cover until the unit was full. Then the vacuum system was shut off and filed down and the unit was removed from the chamber and placed in an oven to cure at a temperature of $65^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for approximately four hours. Finally, it was removed from the oven and the plastic cover taken off (see Figure A18). All excessive RTV on the unit was removed with alcohol, followed with the bolting in place of the metal cover.

TEST DESCRIPTION

ACMU Mounting and Thermal Test

The ACMU was mounted with the power converter and memory on a plate that simulated the spacecraft mounting plate. The entire package was initially thermally tested and found to be satisfactory. It was then ready for official acceptance tests.

The following tests were performed on the unit connected as an integral part of a system as shown in Figure A19.

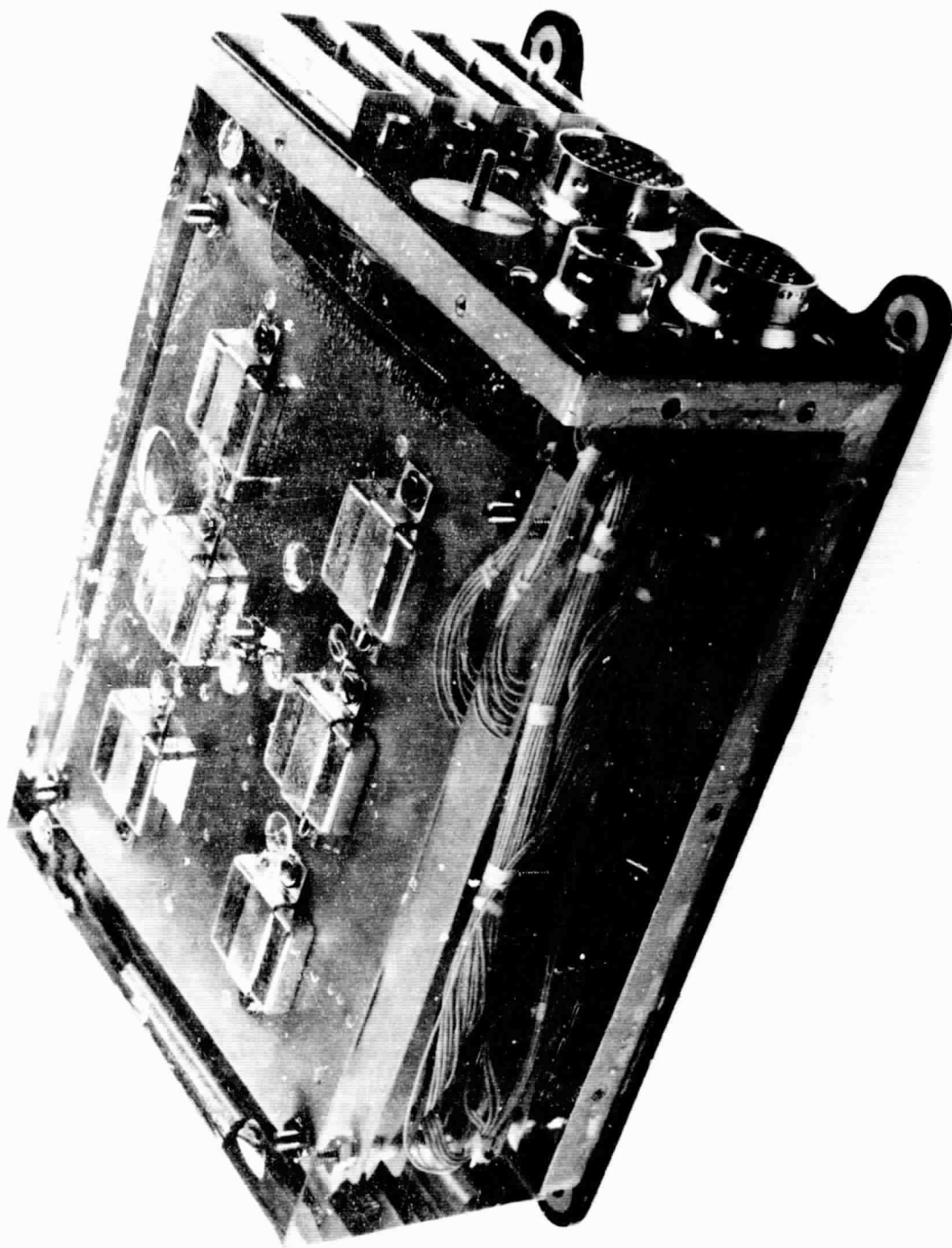


Figure A18. Potted Unit with Plastic Cover Removed

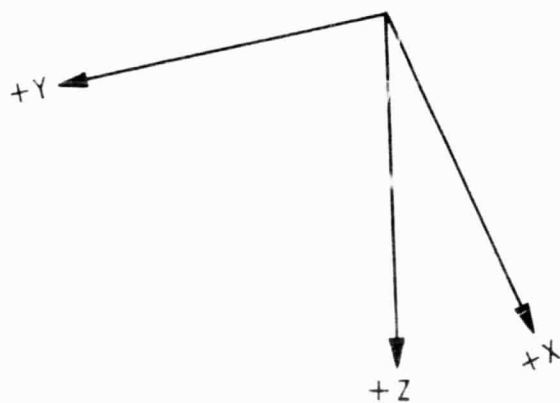
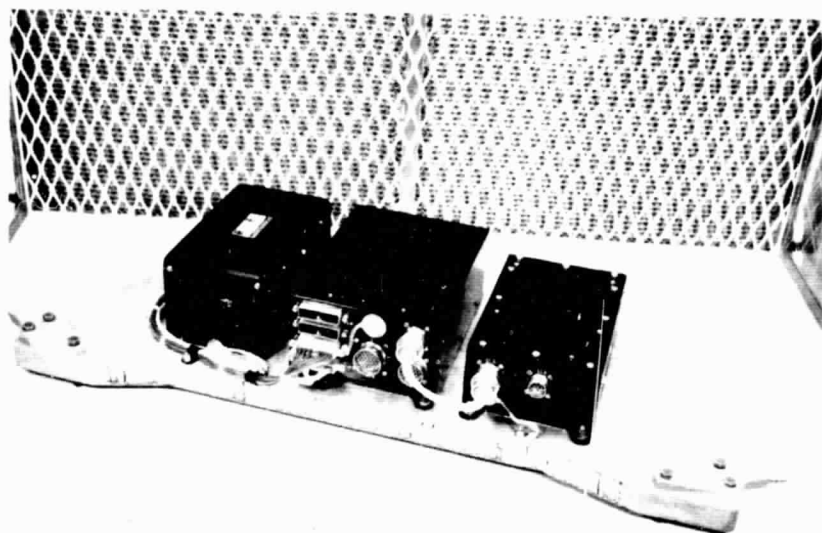


Figure A19. Package Perpendicular Axes Subject to Vibration

Physical Examination

The final package was inspected for conformance to applicable drawings prior to commencement of tests. In addition, it was inspected for workmanship, finish, and any discernable defects. Visual inspection was repeated after each environmental test.

Functional Tests

The functional tests consisted of monitoring all critical input and output current and voltage test points while exercising all modes of operation. These tests were performed on the final package previous to commencement of environmental tests upon completion of vibration and shock tests and after completion of thermal vacuum tests.

Baseline Functional

The package was connected to computer/spacecraft interface equipment and subjected to typical orbital operations, including the exercise of all operating modes.

Environmental Tests

Code 562 Thermal. The package was placed in a temperature chamber and connected to the computer/spacecraft interface equipment. The package and chamber temperature were varied from $80^{\circ}\text{F} \pm 5^{\circ}\text{F}$ to $-30^{\circ}\text{F} \pm 5^{\circ}\text{F}$ to $150^{\circ}\text{F} \pm 5^{\circ}\text{F}$ and back to ambient conditions. A stabilization period of 1 hour at each temperature was instituted before performing the functional tests.

Vibration. Vibration test tolerances were:

- o Sinusoidal vibration amplitude ± 10 percent, vibration frequency ± 2 percent.
- o Random vibration spectral density $\pm 3\text{db}$.
- o $+10$ percent total g rms, -5 percent total g rms.

Sinusoidal vibration was conducted on the specimen in each of the three mutually perpendicular axes shown in Figure A19. The amplitude was varied with frequency, as shown in Table A1 at the rate of four octaves per minute. A plot of amplitude versus frequency was recorded for each axis.

Random vibration was performed over a frequency range of 15 to 2000Hz at the levels given in Table A1 for a period of four minutes per axis. An equalization plot was recorded for each axis.

Two shock pulses were administered along the body axis; one of 30 g magnitude and 6 ms duration, and one of 30 g magnitude and 12 ms duration.

Thermal Vacuum. The package mounting plate served as the control surface and was heated by thermal pads placed in contact with the unused side. The five exposed surfaces were covered with 25 layers of space-craft insulation and the themocouple temperatures and chamber pressure were recorded at 30 minute intervals.

The package with power applied was placed in a temperature vacuum chamber and subjected to a vacuum of 10^{-6} mm Hg. The heat sink temperature was varied from $80^{\circ}\text{F} \pm 5^{\circ}\text{F}$ to $-30^{\circ}\text{F} \pm 5^{\circ}\text{F}$ at a rate of 3°F per minute. The total length of time at each temperature was no less than 24 hours and during this period the functional tests were performed 3 times. After these excursions, the heat sink temperature was raised to $80^{\circ}\text{F} \pm 5^{\circ}\text{F}$ at a maximum rate of 30°F per minute, and, after a period of 1 hour at this temperature, the functional tests were performed. The chamber was then returned to ambient conditions, and, after a period of 1 hour, the functional tests were performed again.

Table A3

SINUSOIDAL/RANDOM VIBRATION LEVELS

Sinusoidal		Random	
Frequency	Level	Frequency	Level
5-20Hz	1/2 inch DA	15Hz	$0.010 \text{ g}^2/\text{Hz}$
20-110Hz	10.0 g Peak	15-70Hz	Linear Increase
110-2000Hz	5.0 g Peak	70-100Hz	$0.31 \text{ g}^2/\text{Hz}$
		100-400Hz	Linear Decrease
		400-2000Hz	$0.02 \text{ g}^2/\text{Hz}$